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(54) **HYBRID VEHICLE PROPULSION ENERGY STORAGE SYSTEM**

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(51) **Int. Cl.**
H01G 9/00 (2006.01)

(52) **U.S. Cl.** **361/502**; 361/503; 361/504; 361/509; 361/512; 361/517

(58) **Field of Classification Search** 361/502, 361/503–504, 509–512, 516–519, 523–528, 361/535–538, 328–330, 303–305
See application file for complete search history.

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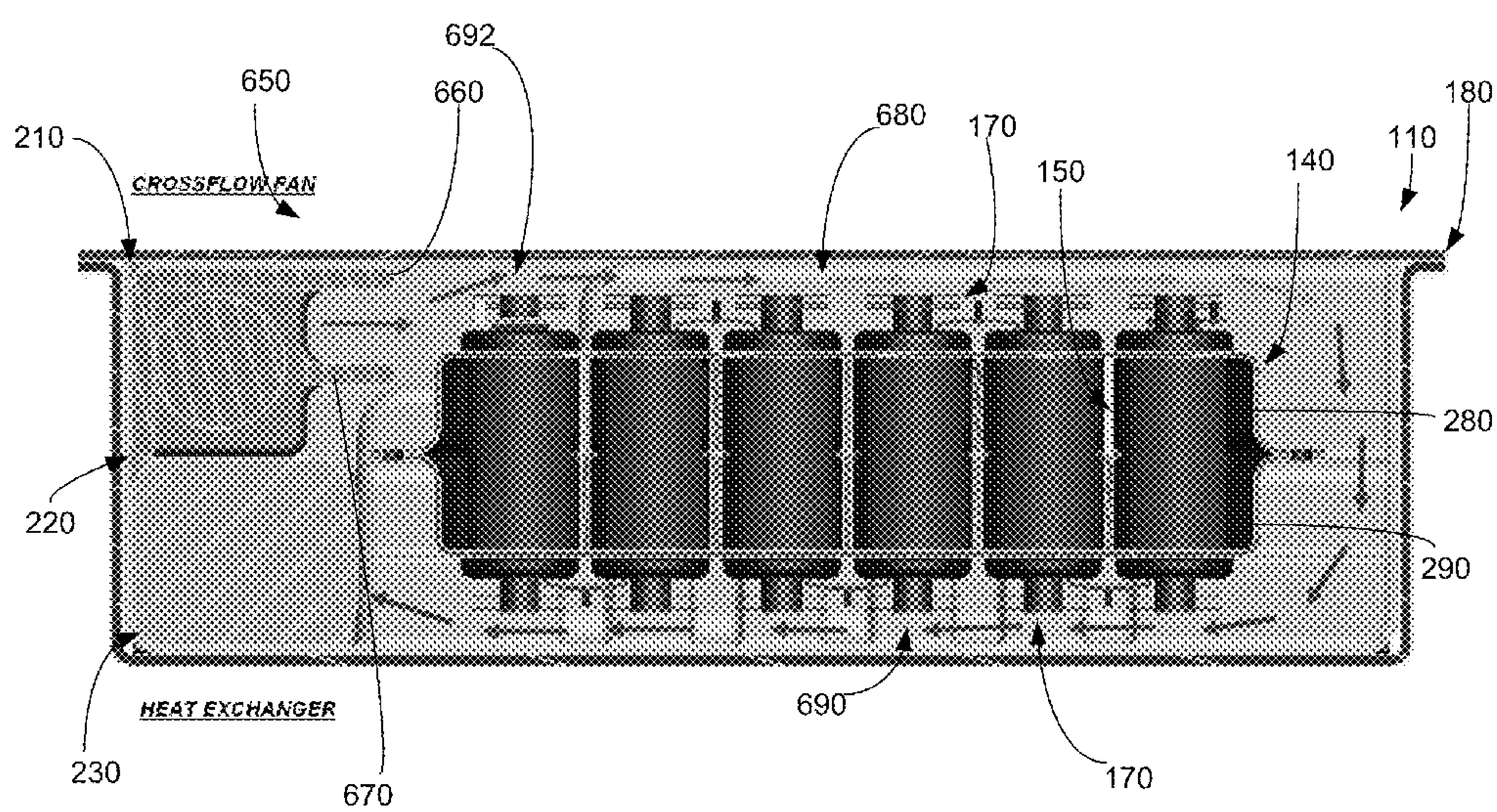
(74) *Attorney, Agent, or Firm*—Stephen C. Beuerle; Procopio Cory Hargreaves & Savitch LLP

(57) **ABSTRACT**

An energy storage cell pack cradle assembly for holding multiple rows of energy storage cells oriented along a dominant axis of vibration includes a first cradle member including a plurality of energy storage cell body supporting structures including respective holes; a second cradle member including a plurality of energy storage cell body supporting structures including respective holes; and one or more fasteners connecting the first cradle member and the second cradle member together. The energy storage cell body supporting structures are configured to structurally support the energy storage cells, with the energy storage cells oriented along a dominant axis of vibration, by energy storage cell bodies of the energy storage cells with respective electrically conductive terminals extending through the respective holes without structural support of the electrically conductive terminals by the cradle members.

20 Claims, 16 Drawing Sheets



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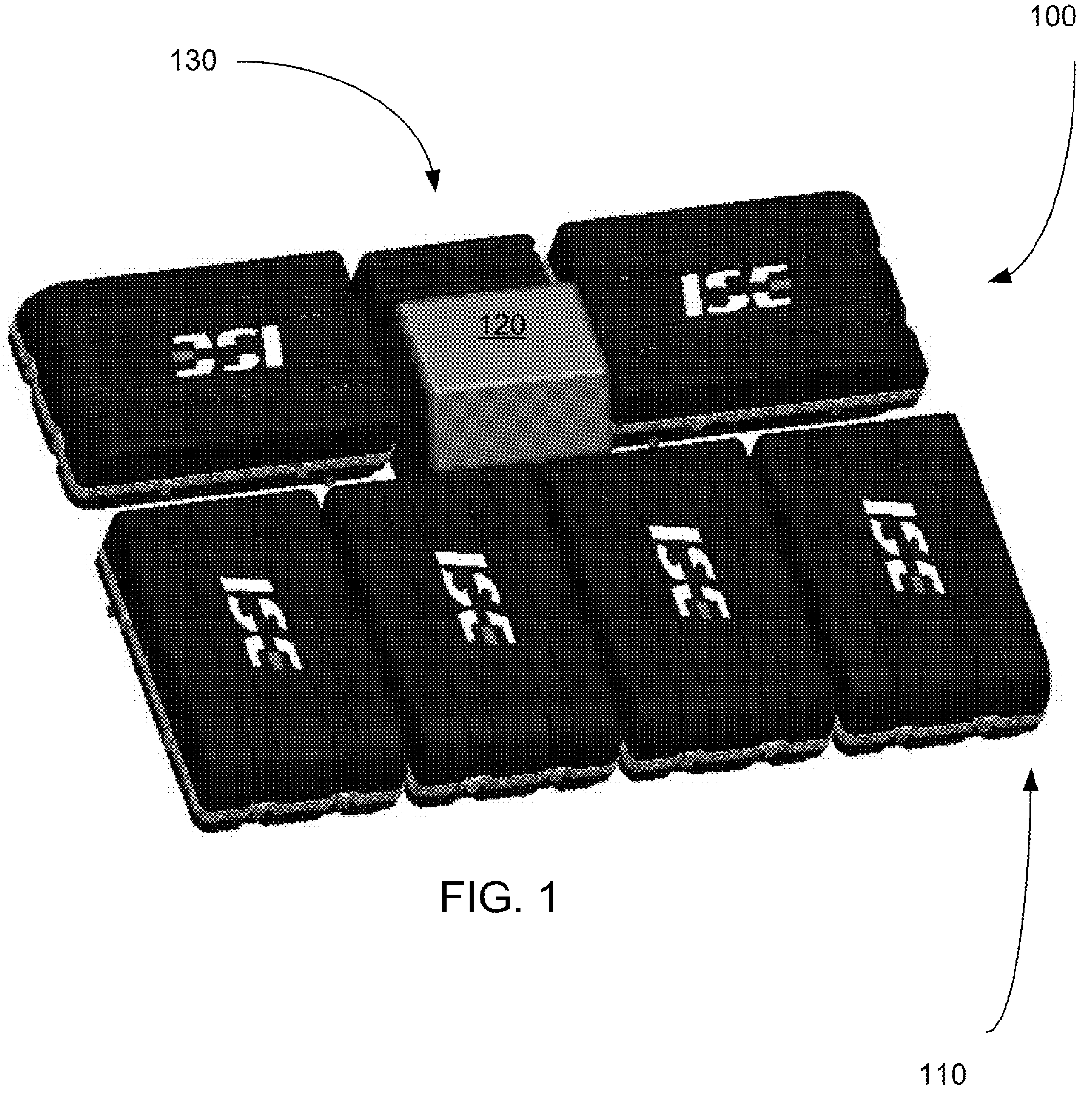


FIG. 1

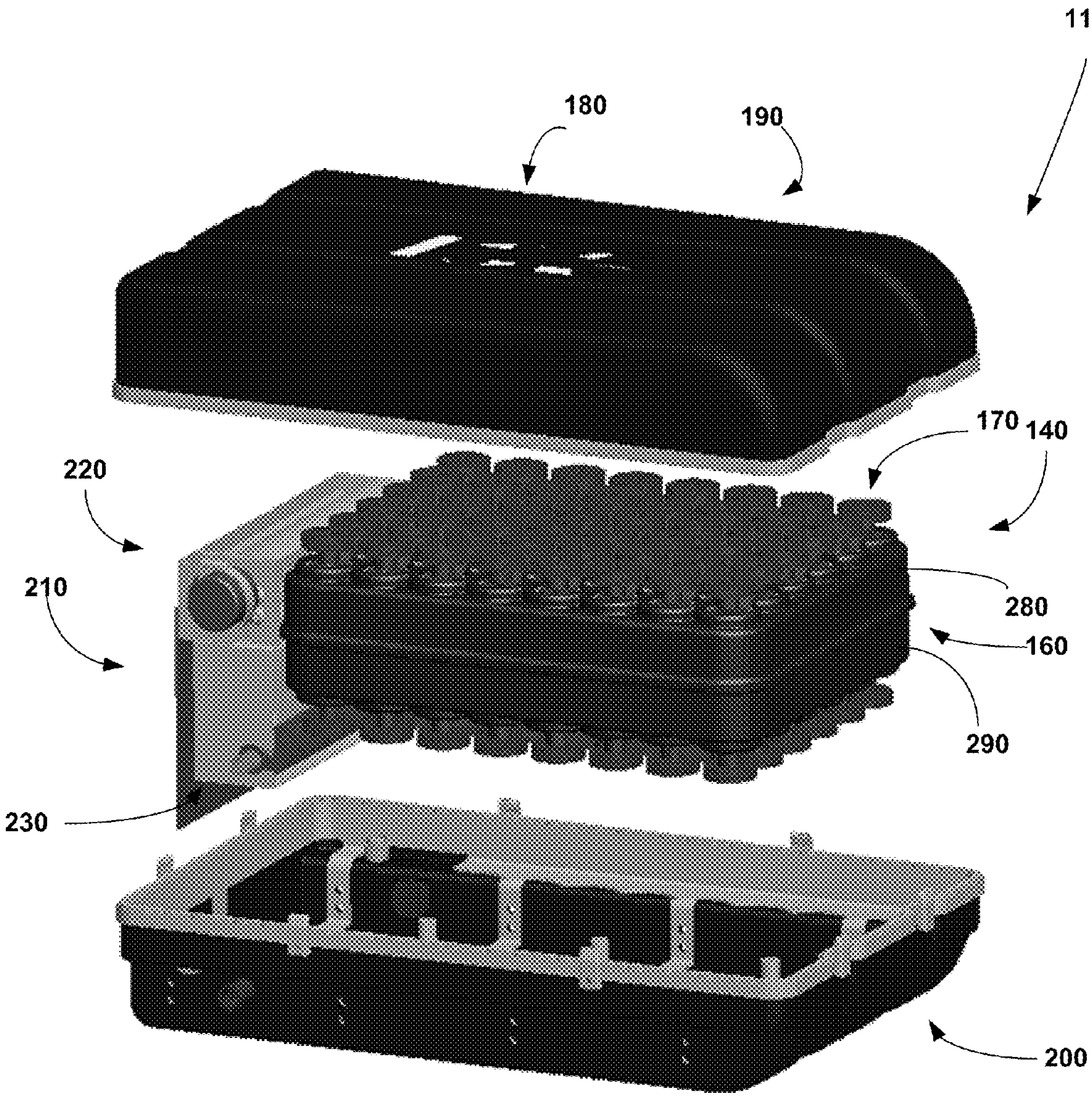


FIG. 2

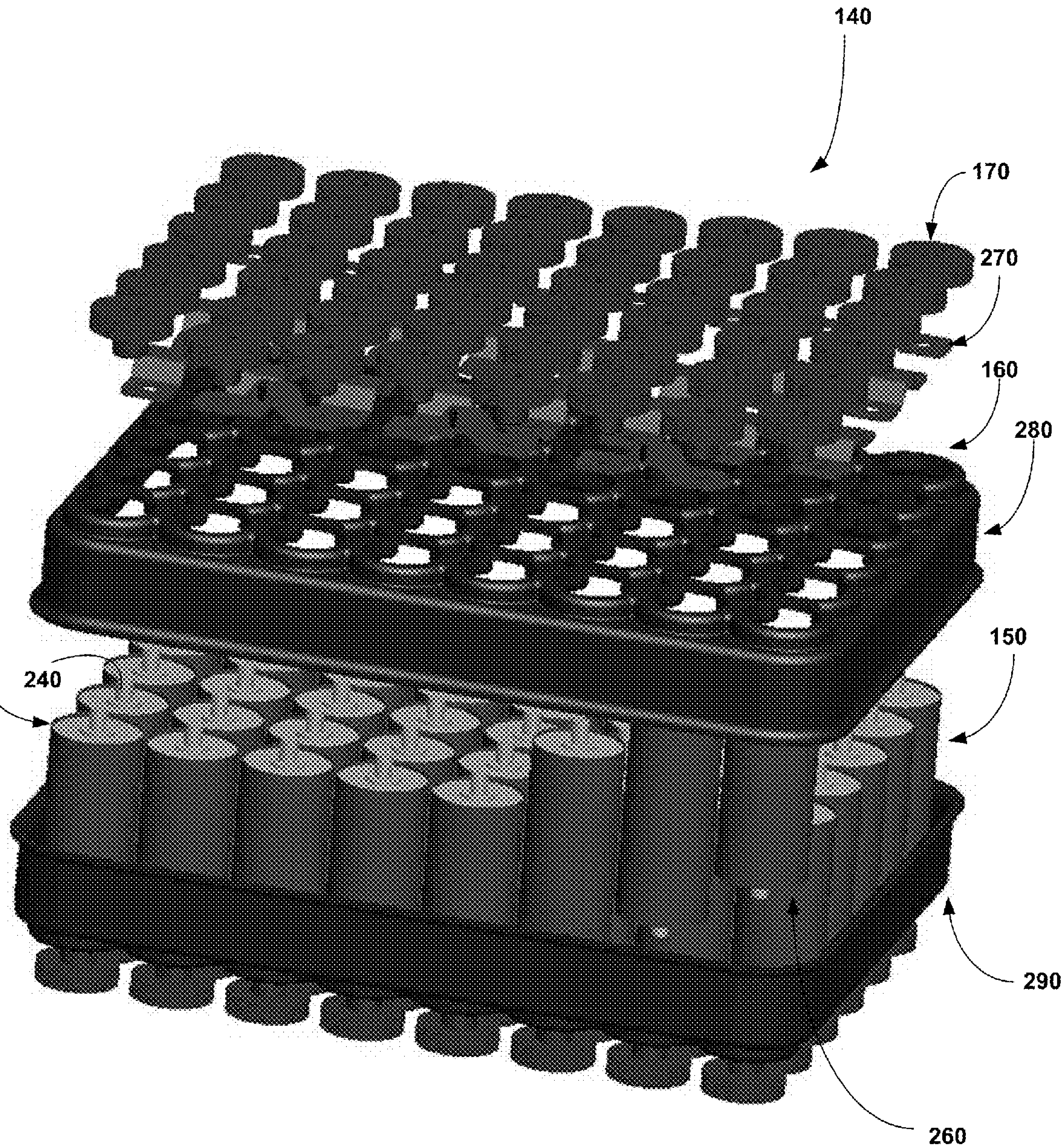


FIG. 3

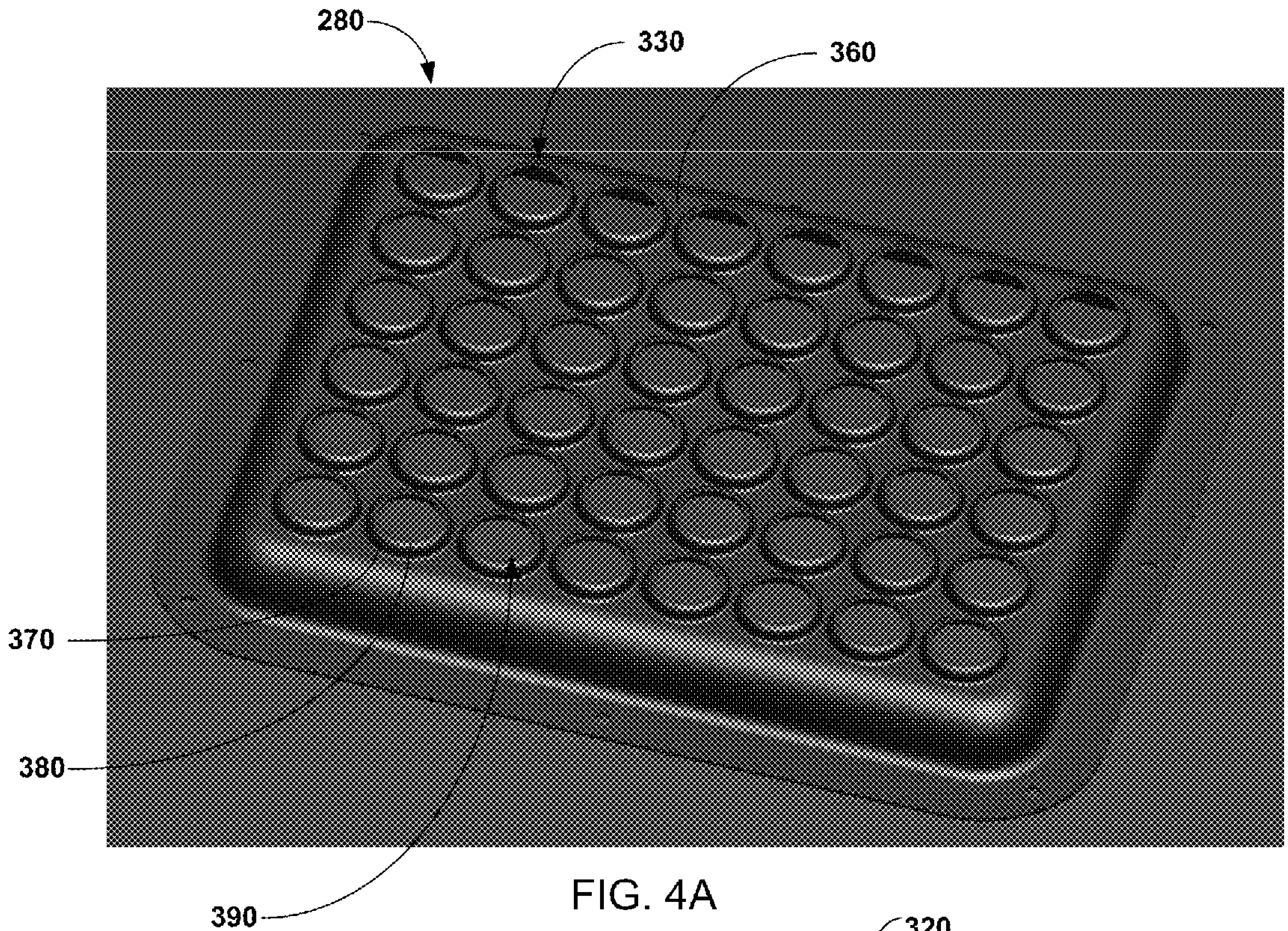


FIG. 4A

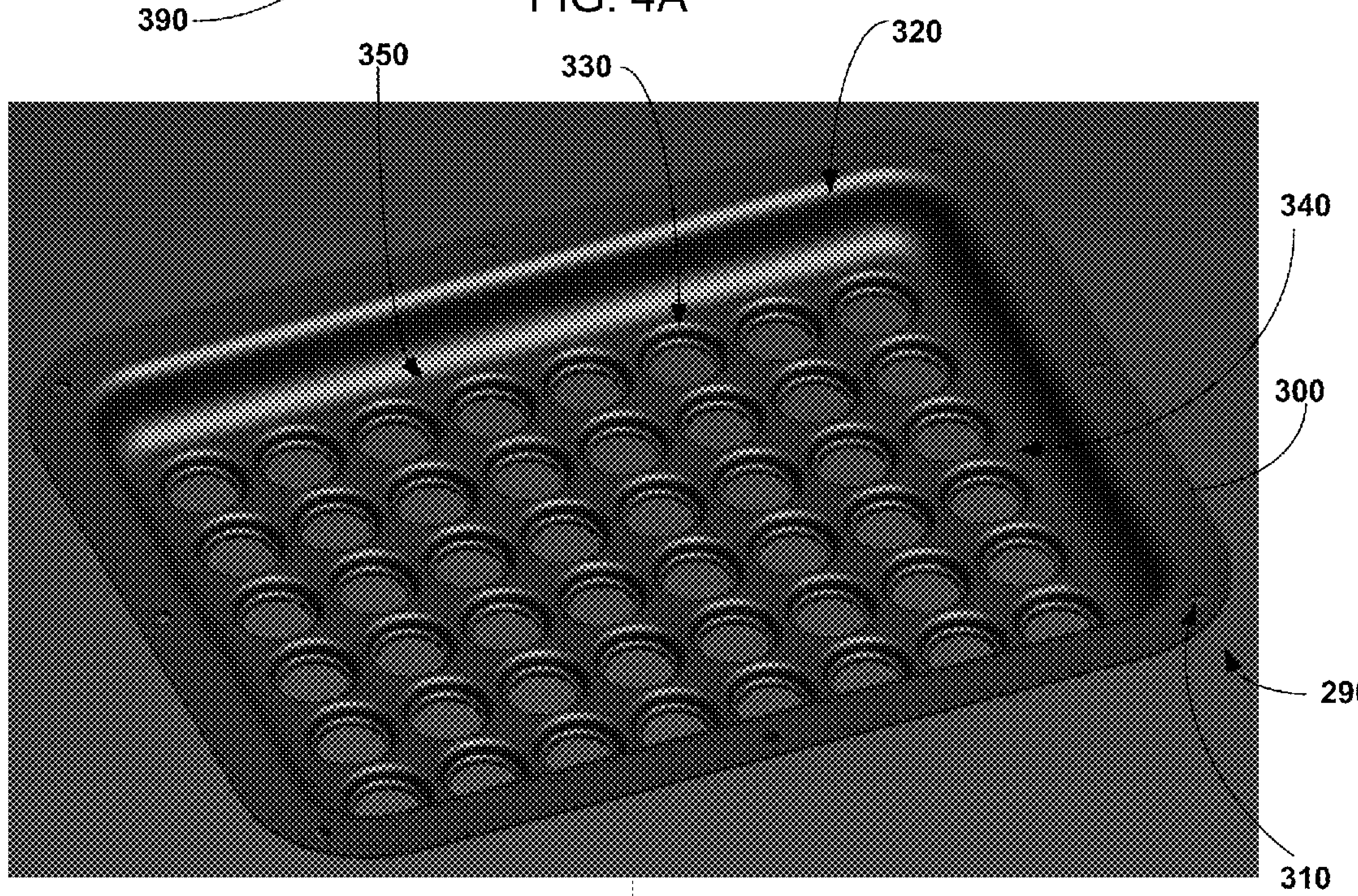


FIG. 4B

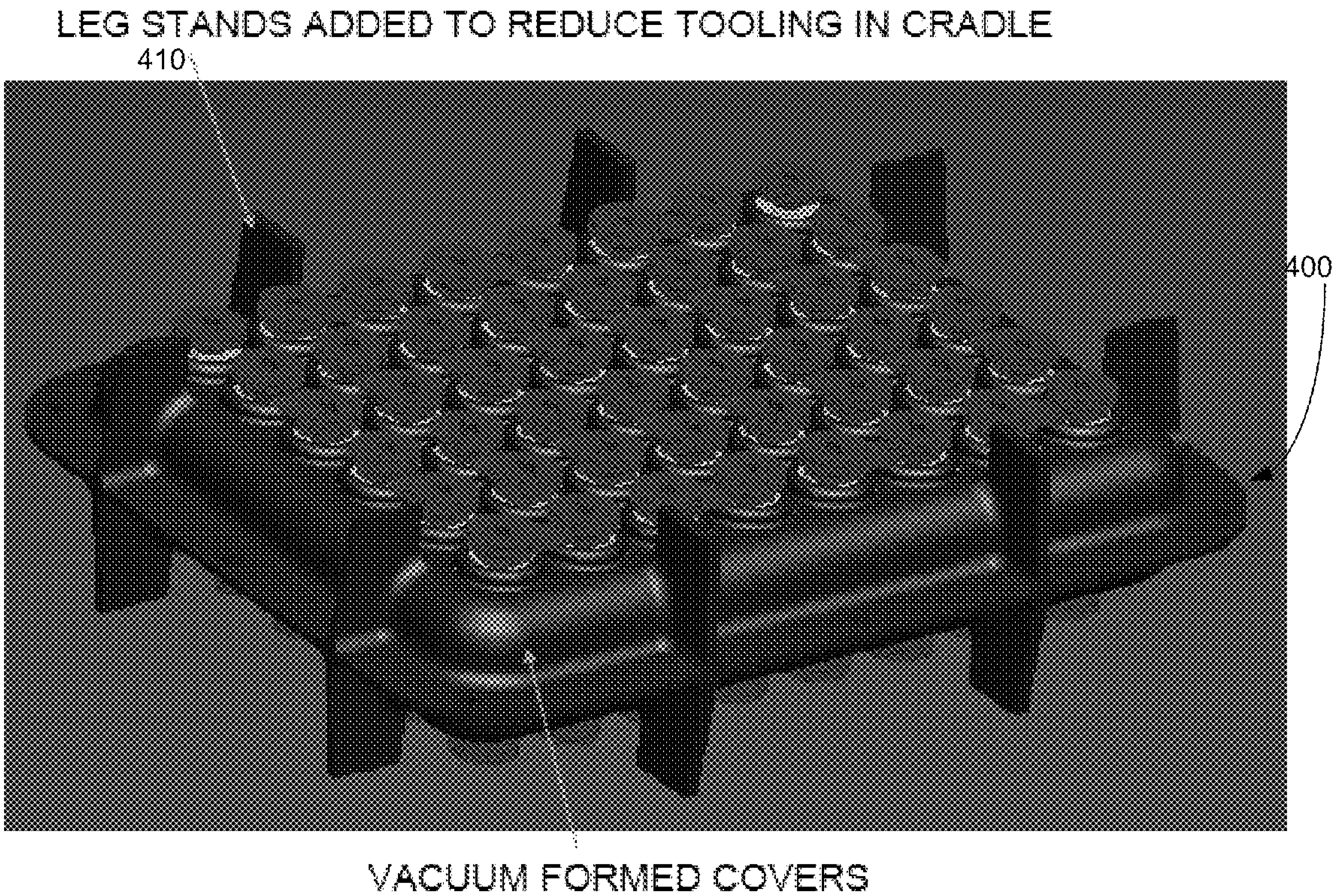

LEG STANDS ADDED TO REDUCE TOOLING IN CRADLE
410
400
VACUUM FORMED COVERS

FIG. 5

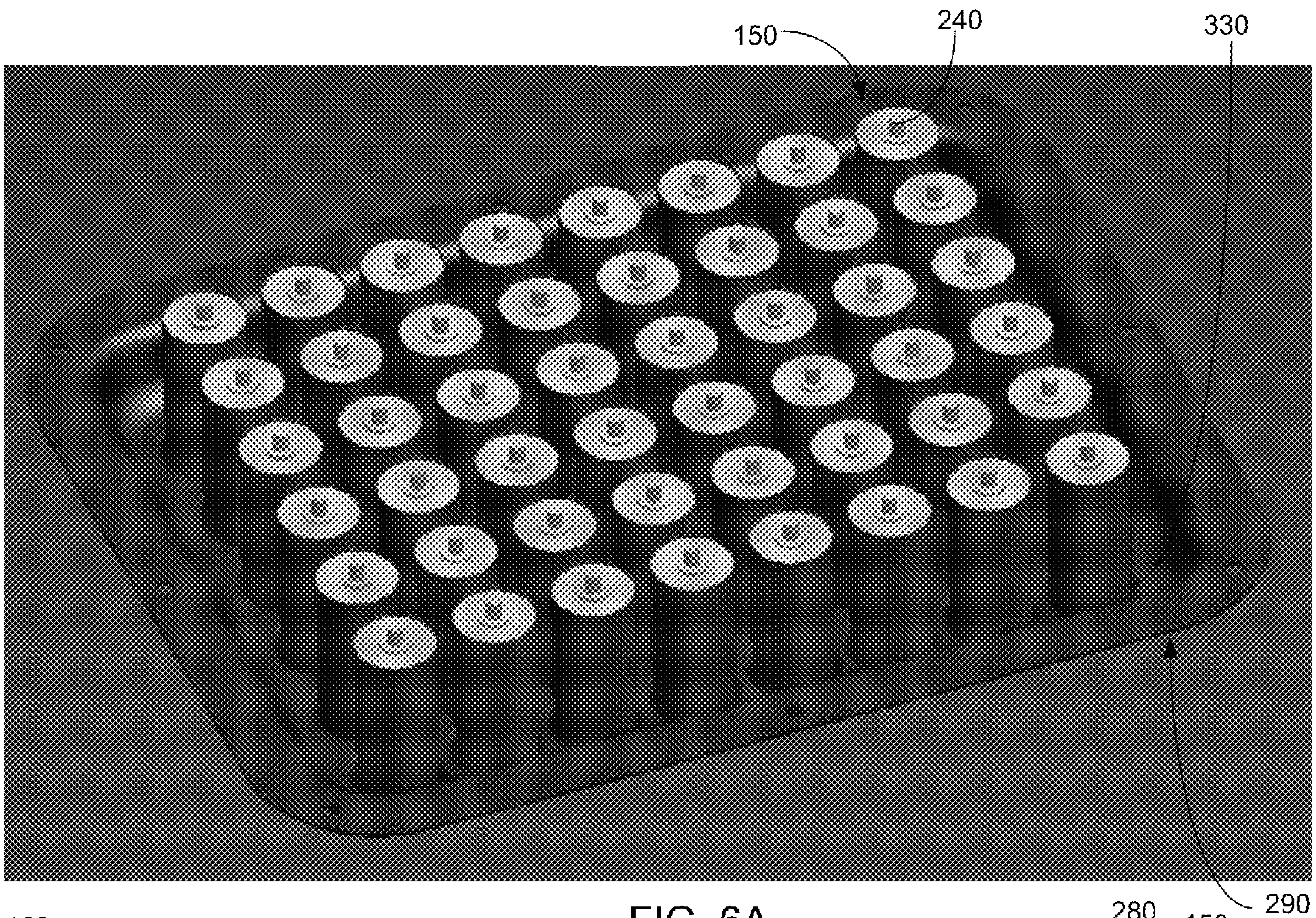


FIG. 6A

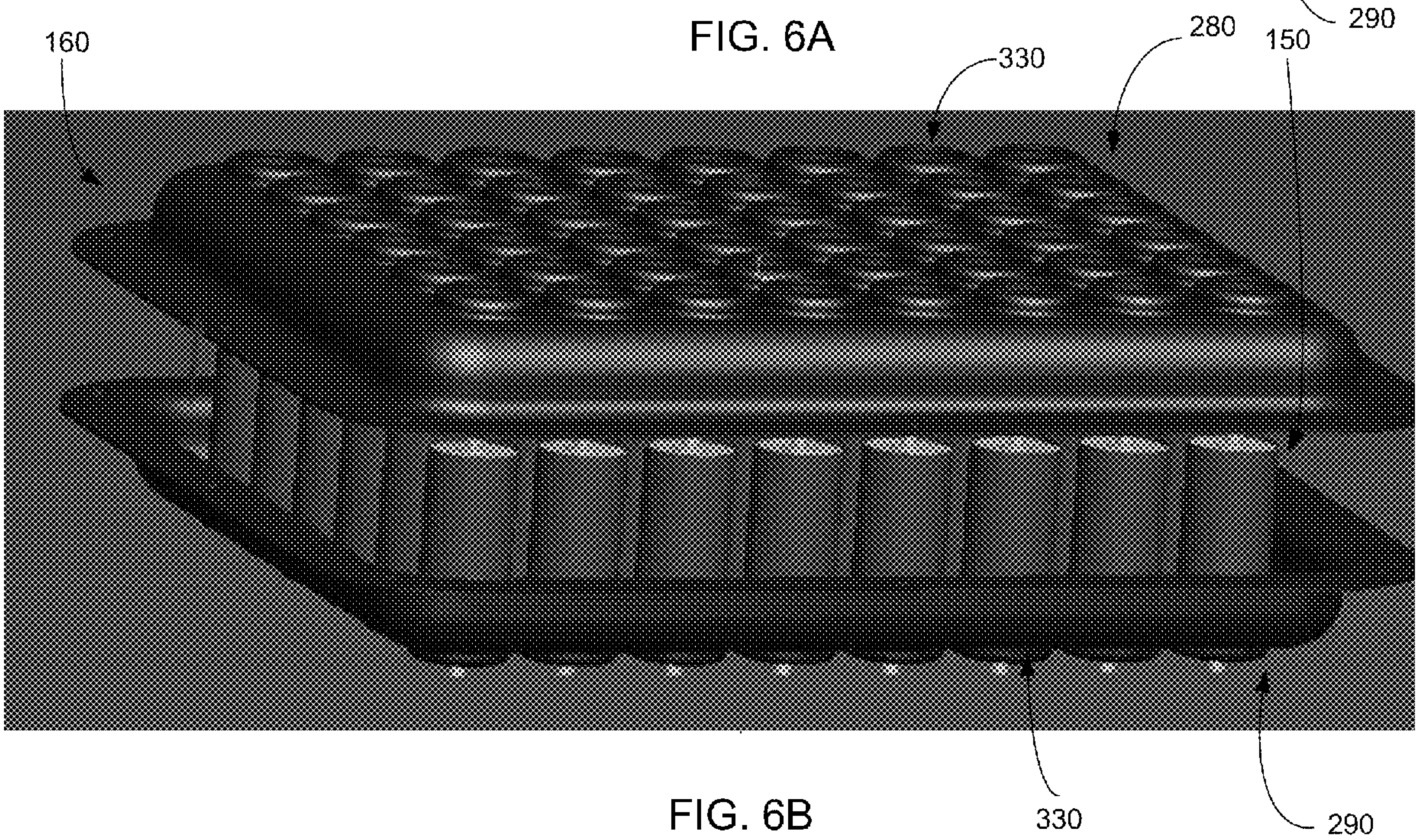


FIG. 6B

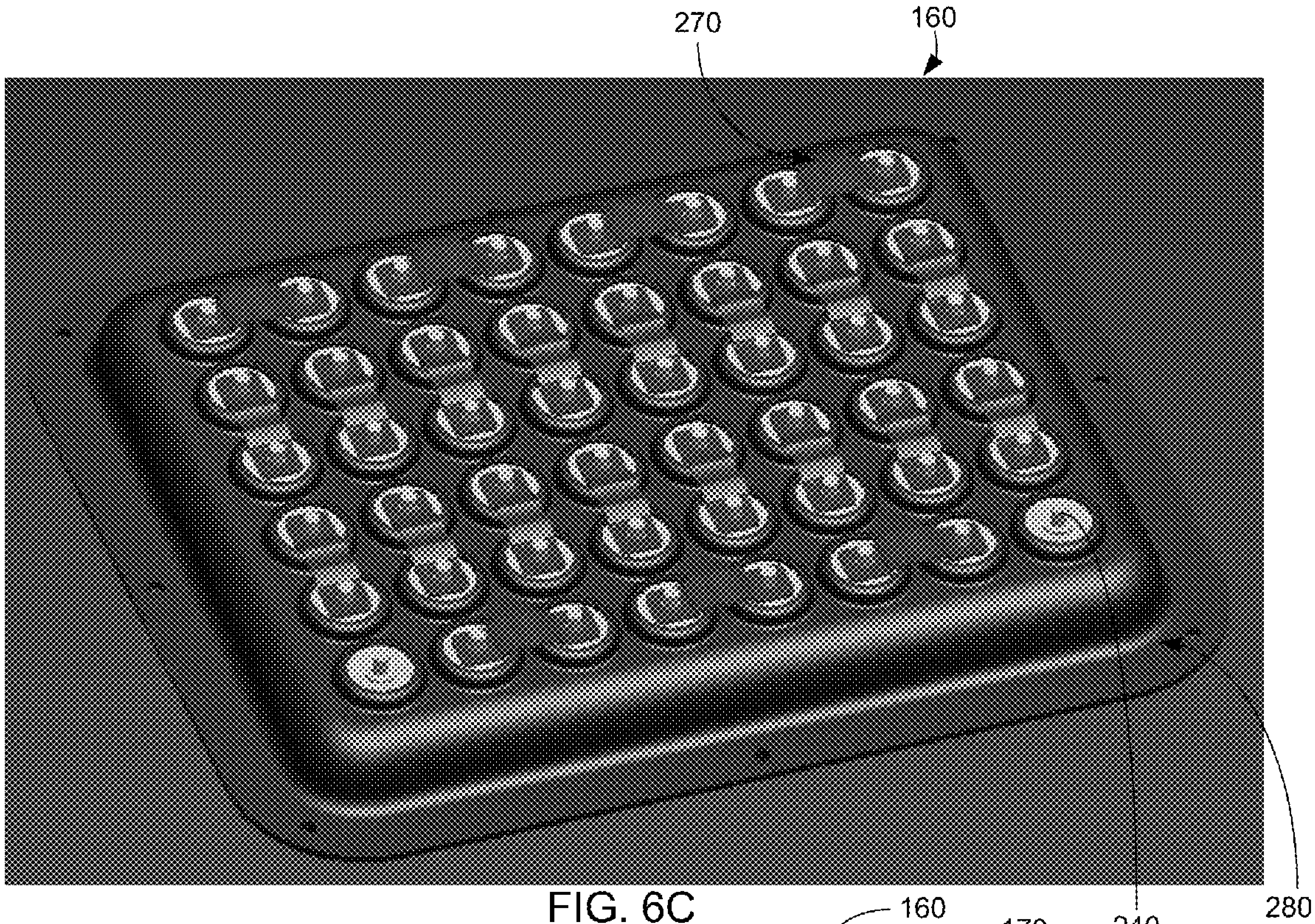


FIG. 6C

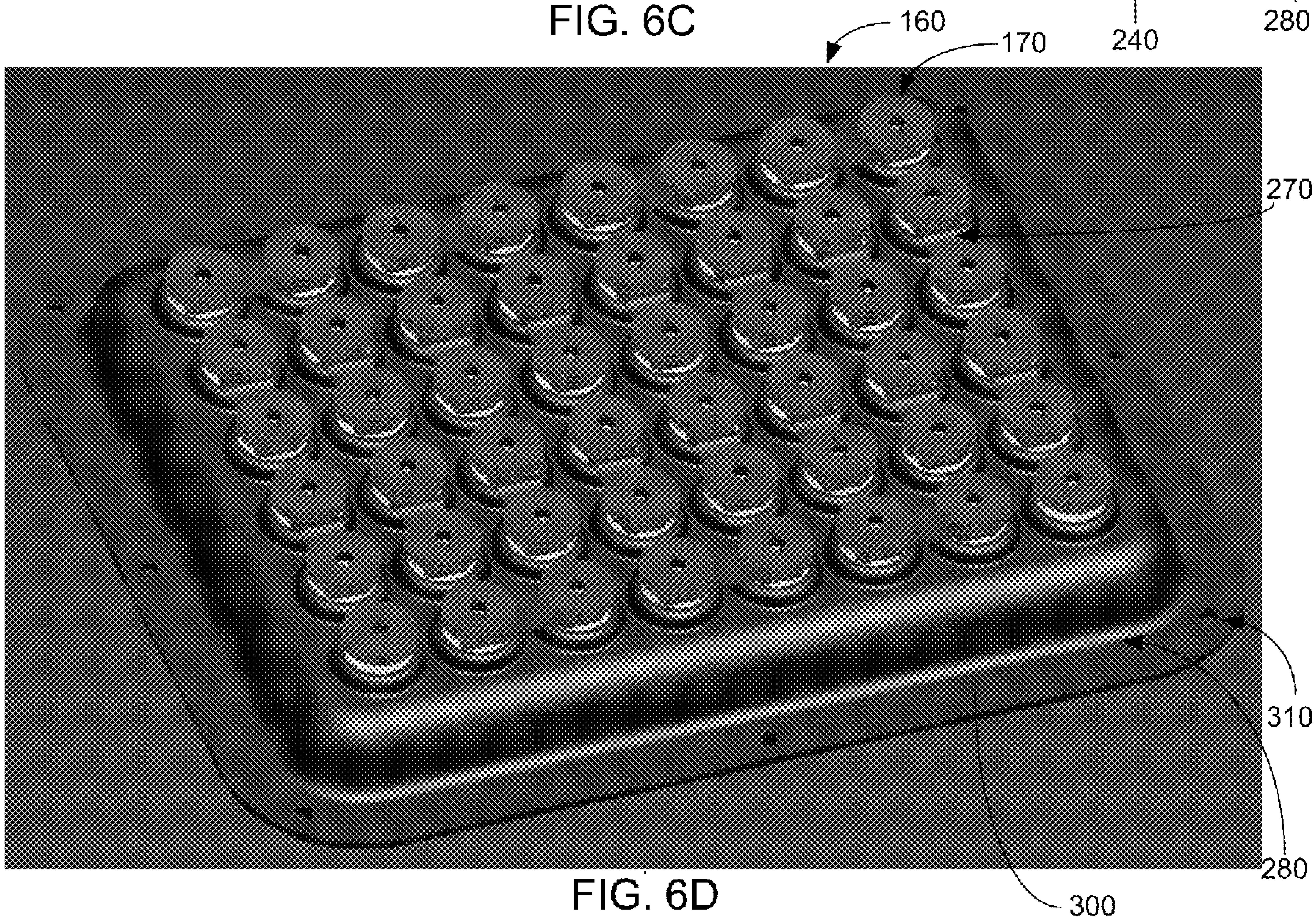


FIG. 6D

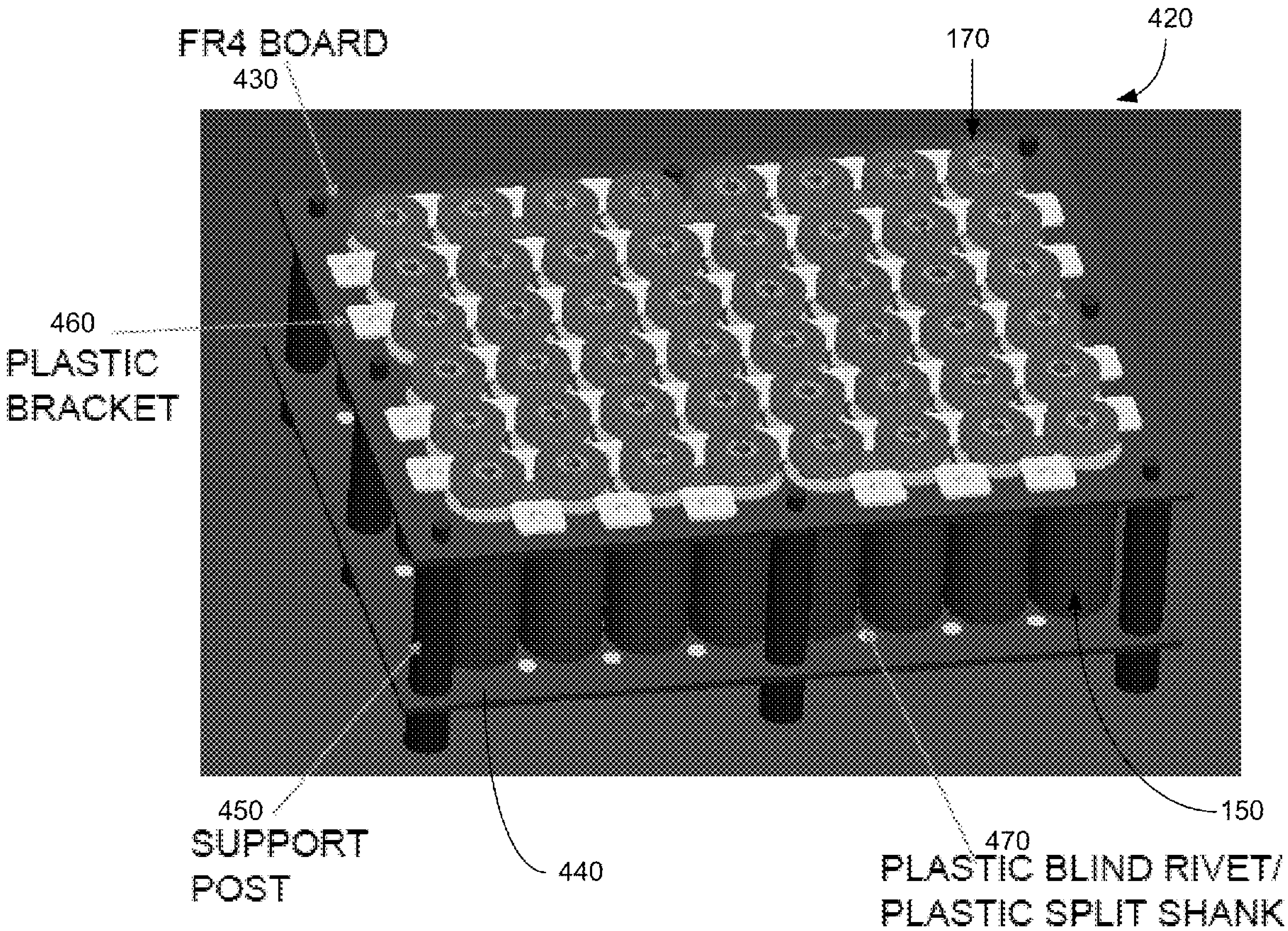

FR4 BOARD
430
170
420
460
PLASTIC
BRACKET
450
SUPPORT
POST
440
470
PLASTIC BLIND RIVET/
PLASTIC SPLIT SHANK
150

FIG. 7

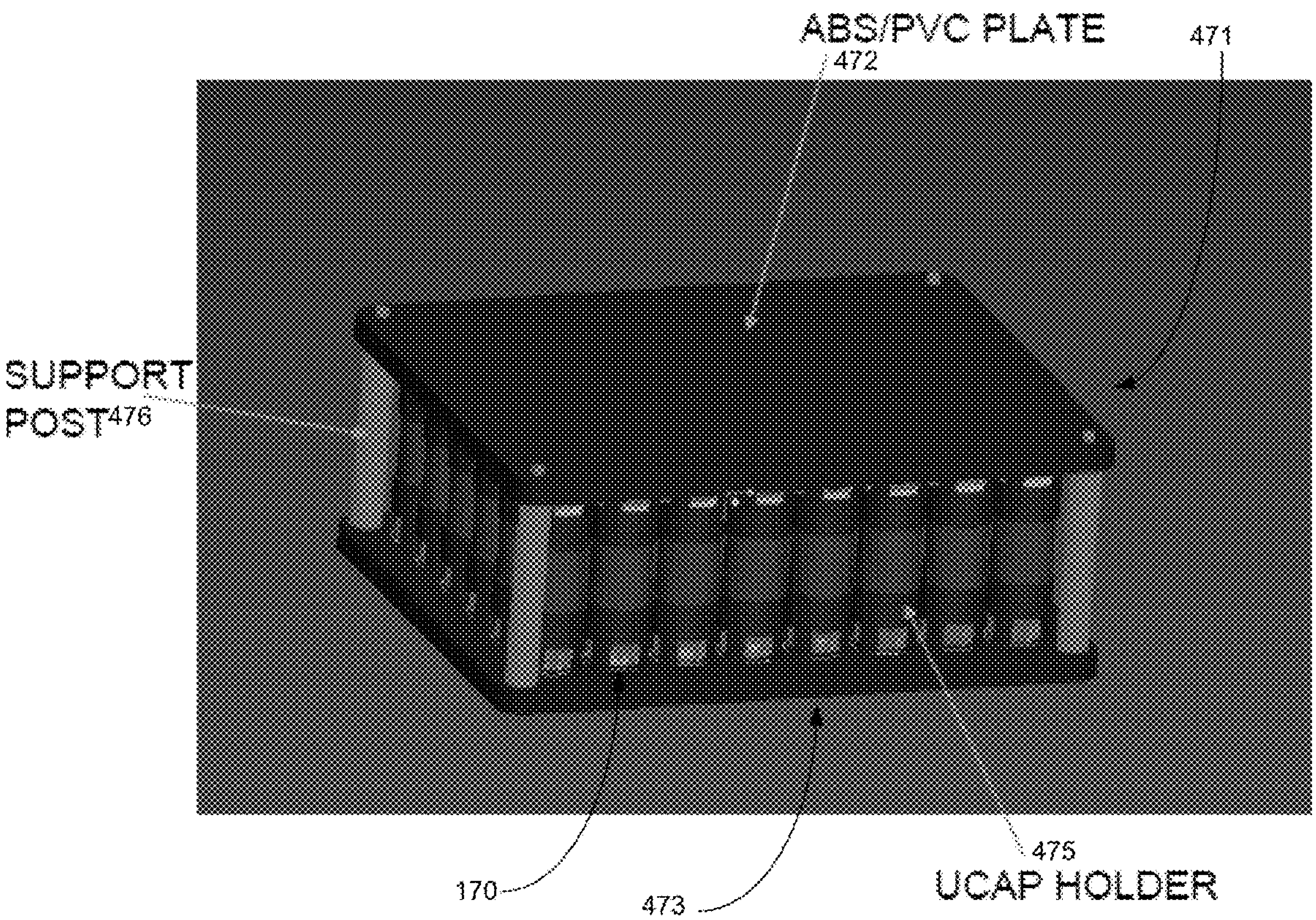

ABS/PVC PLATE
472
471
SUPPORT
POST476
170
473
475
UCAP HOLDER

FIG. 8A

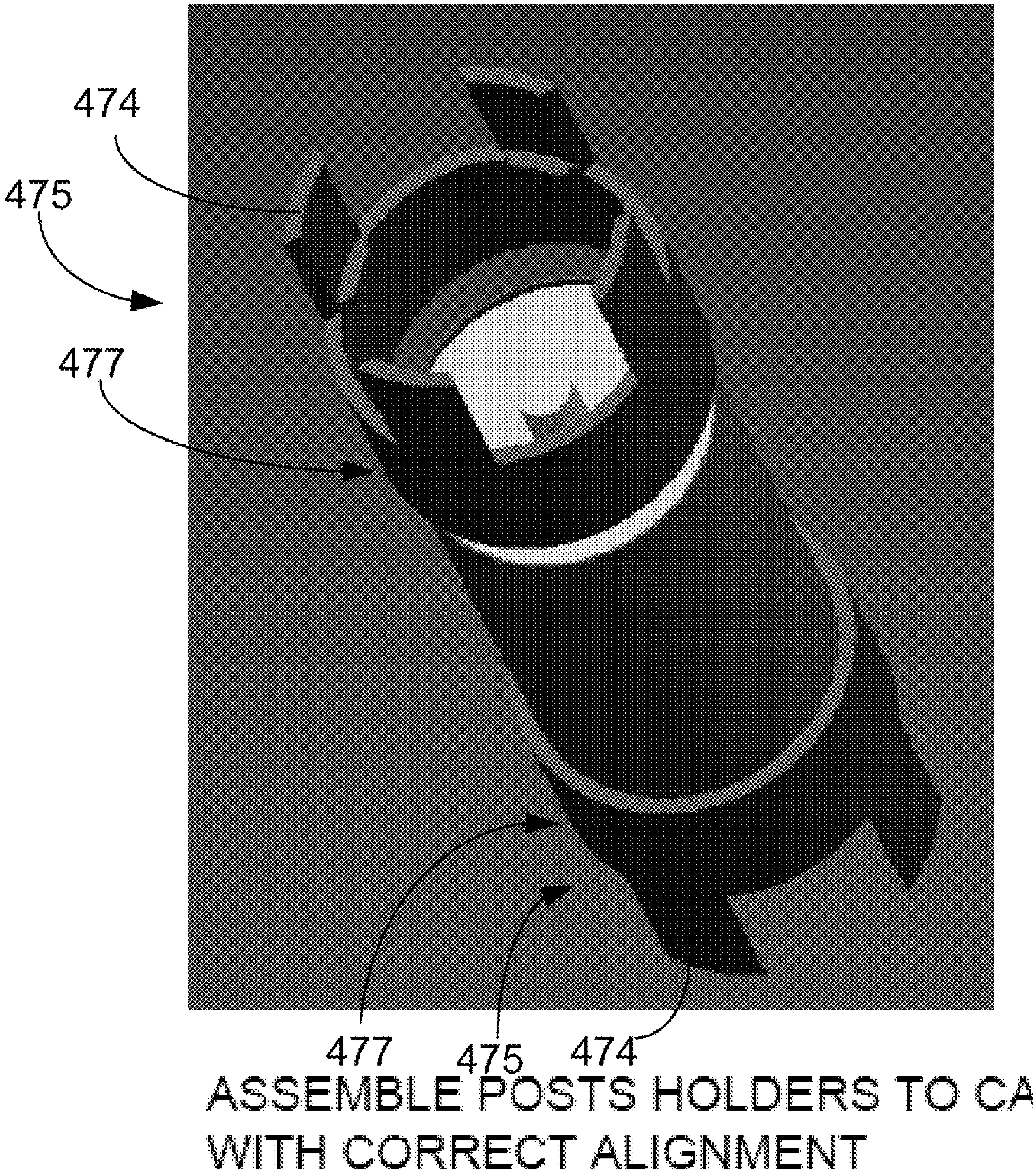

474
475
477
477
475
474
ASSEMBLE POSTS HOLDERS TO CA
WITH CORRECT ALIGNMENT

FIG. 8B

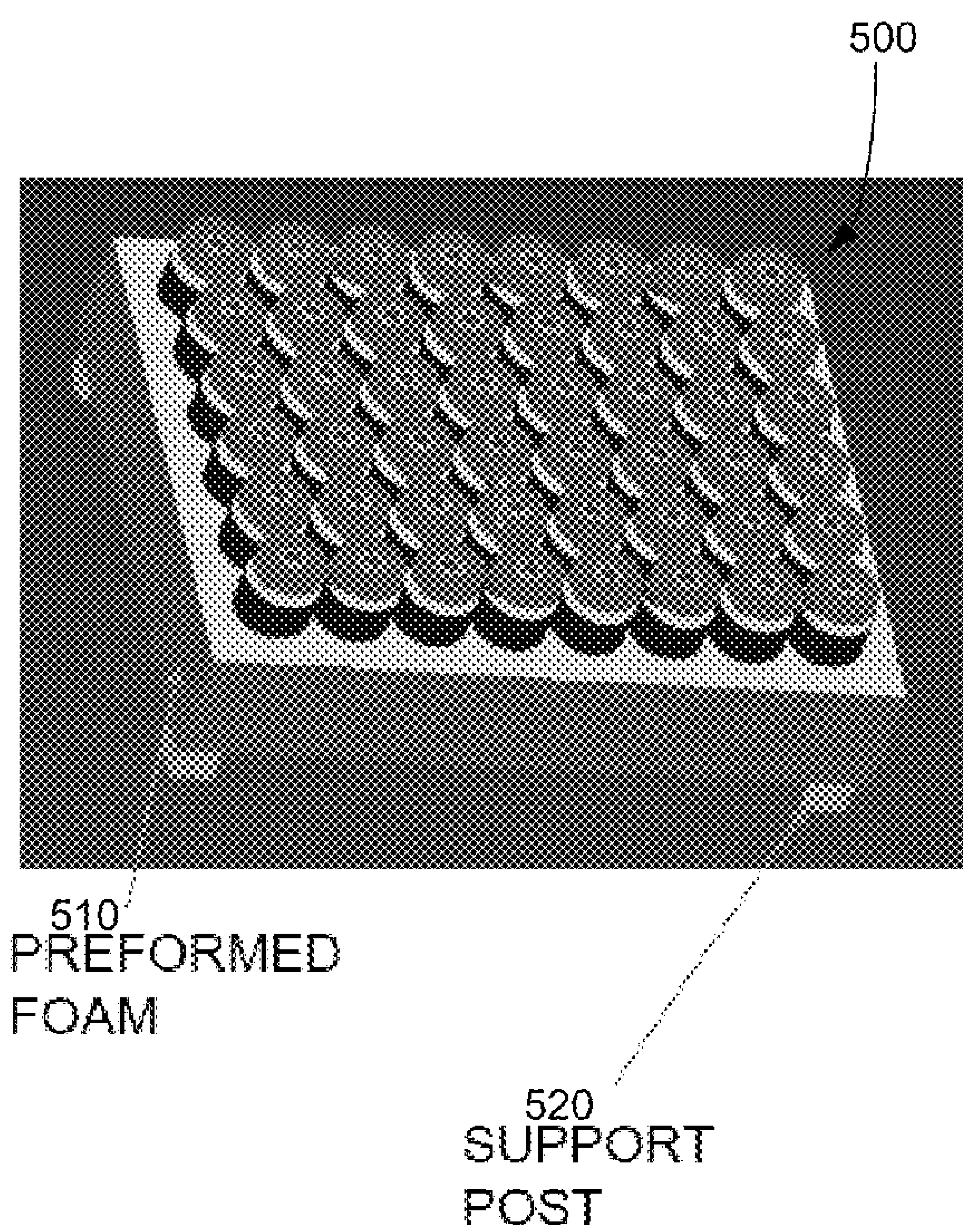

500
510
PREFORMED
FOAM
520
SUPPORT
POST

FIG. 9A

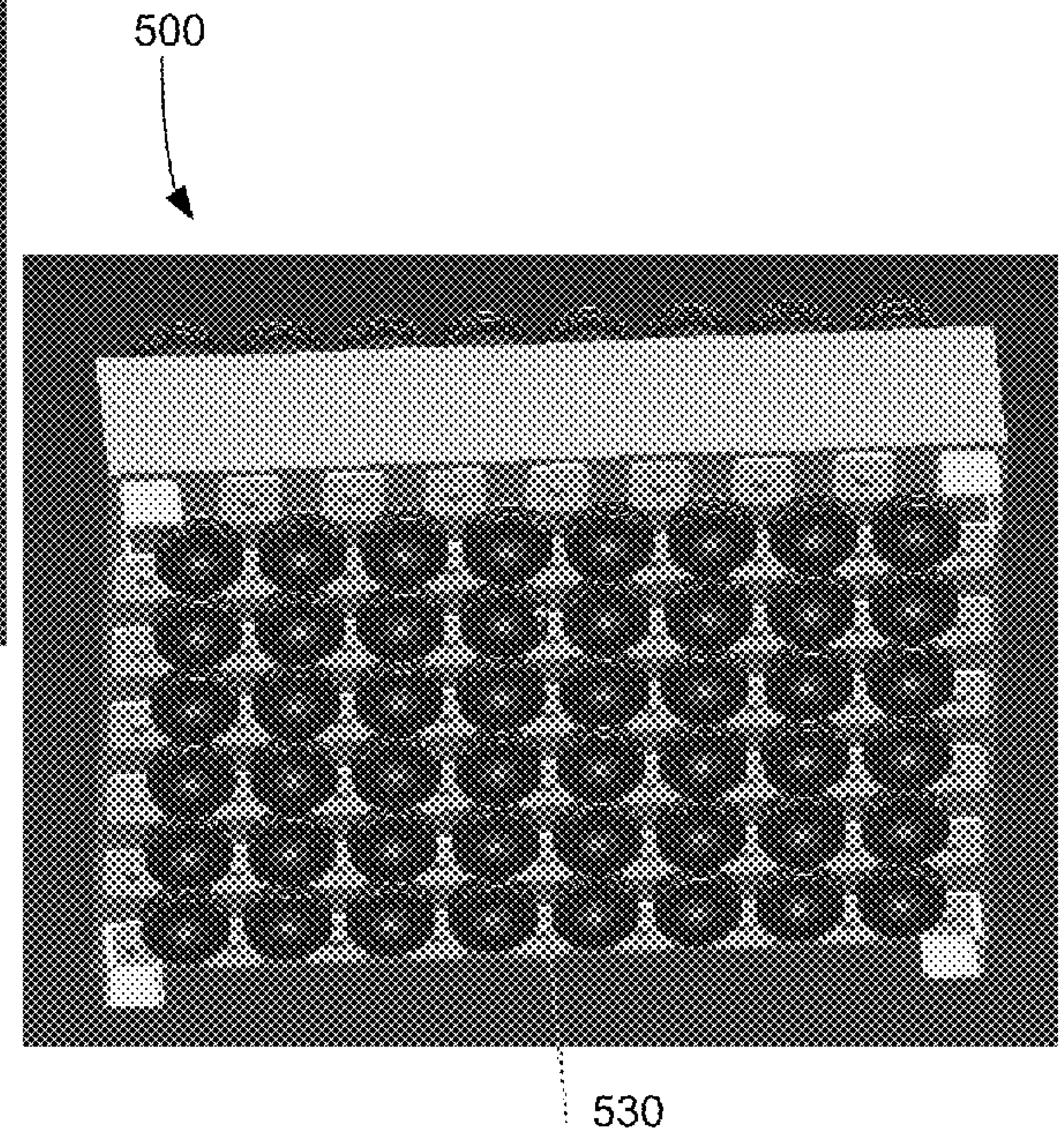

500
530
END BRACKETS WITH SCREWS

FIG. 9B

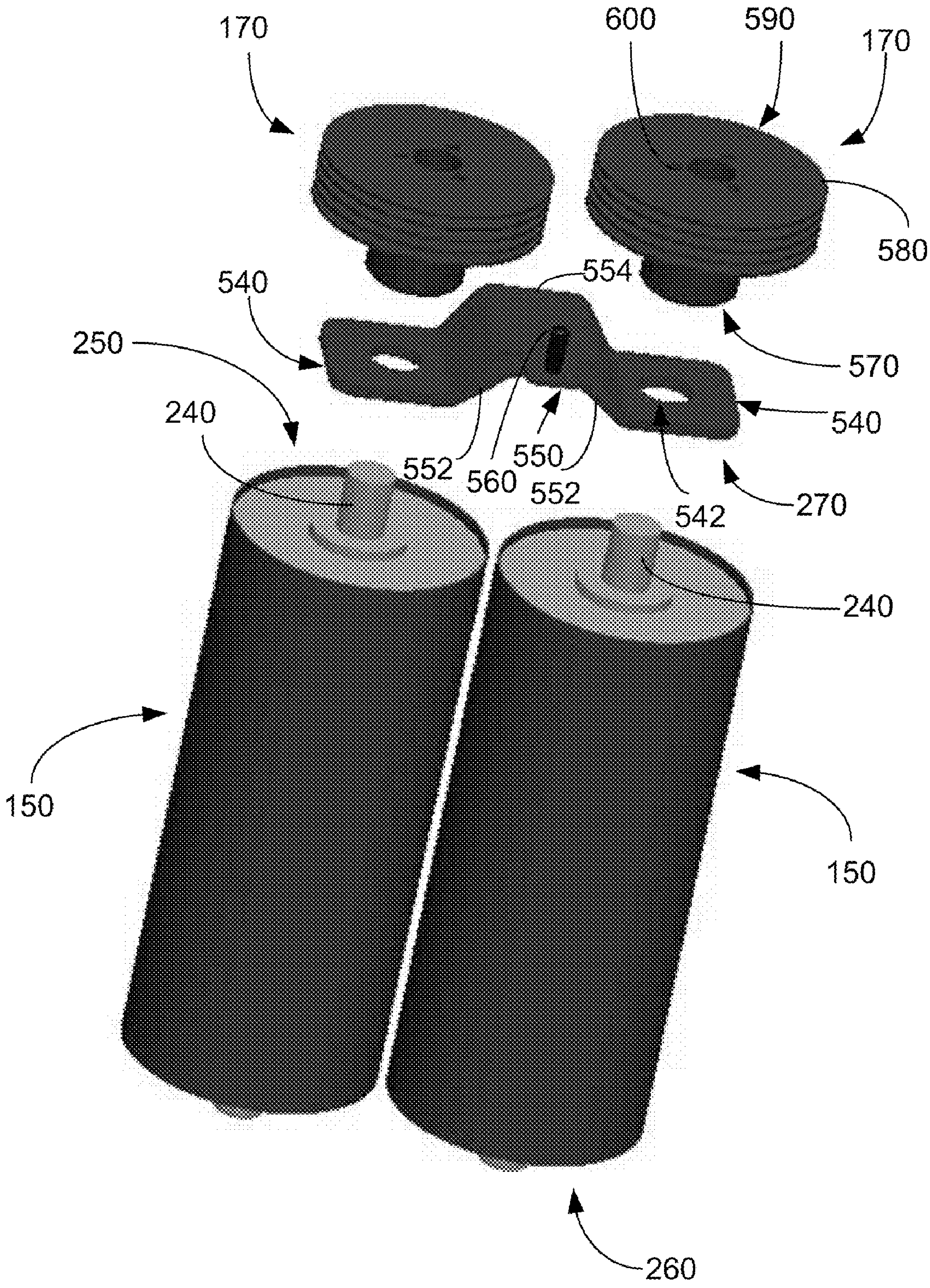

170
600
590
170
580
554
540
570
250
540
240
552
550
560
552
542
270
240
150
150
260

FIG. 10

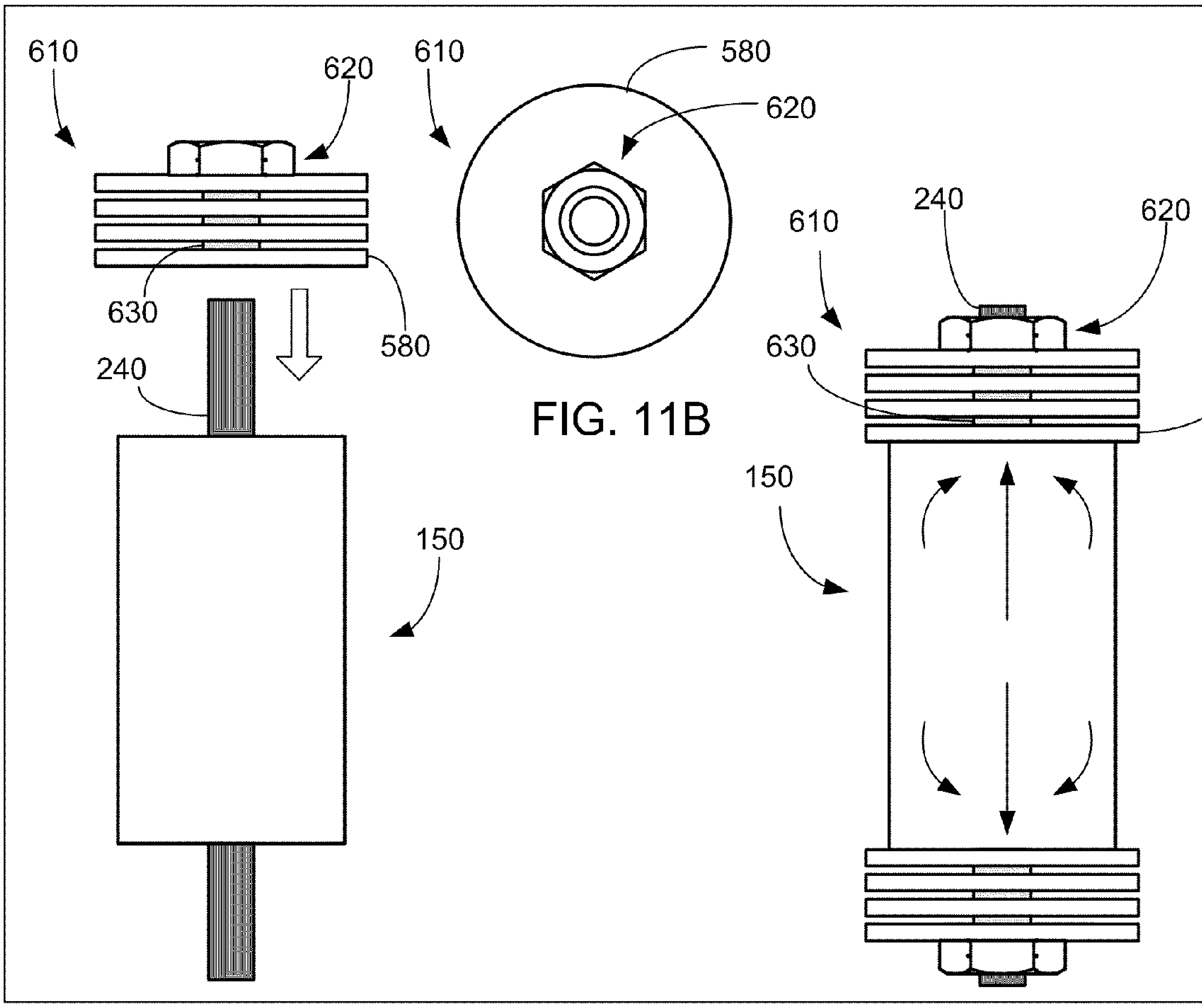
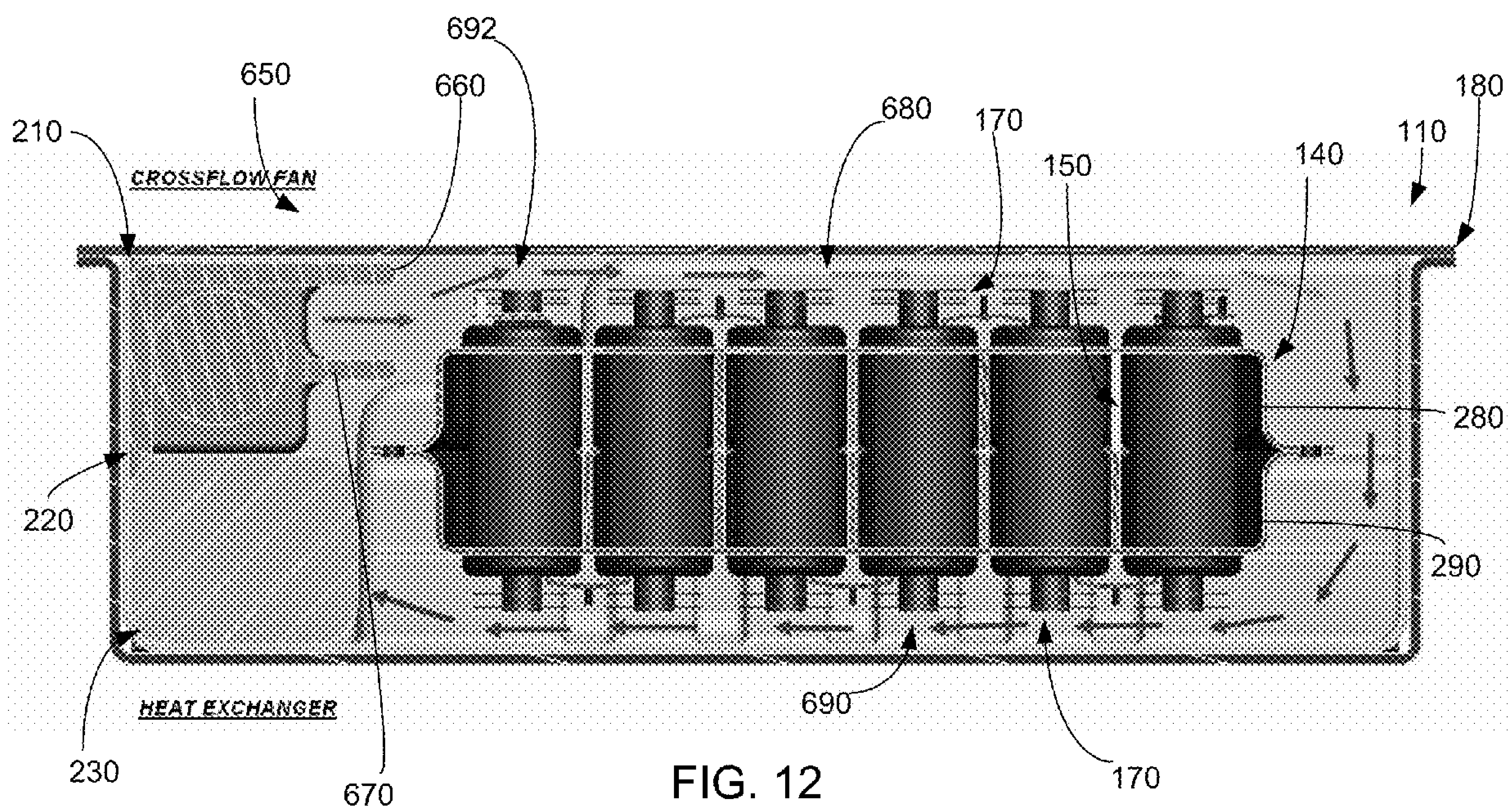


FIG. 11A

FIG. 11C



692
650
660
680
170
180
210
110
150
140
CROSSFLOW FAN
280
220
290
HEAT EXCHANGER
690
230
670
170

FIG. 12

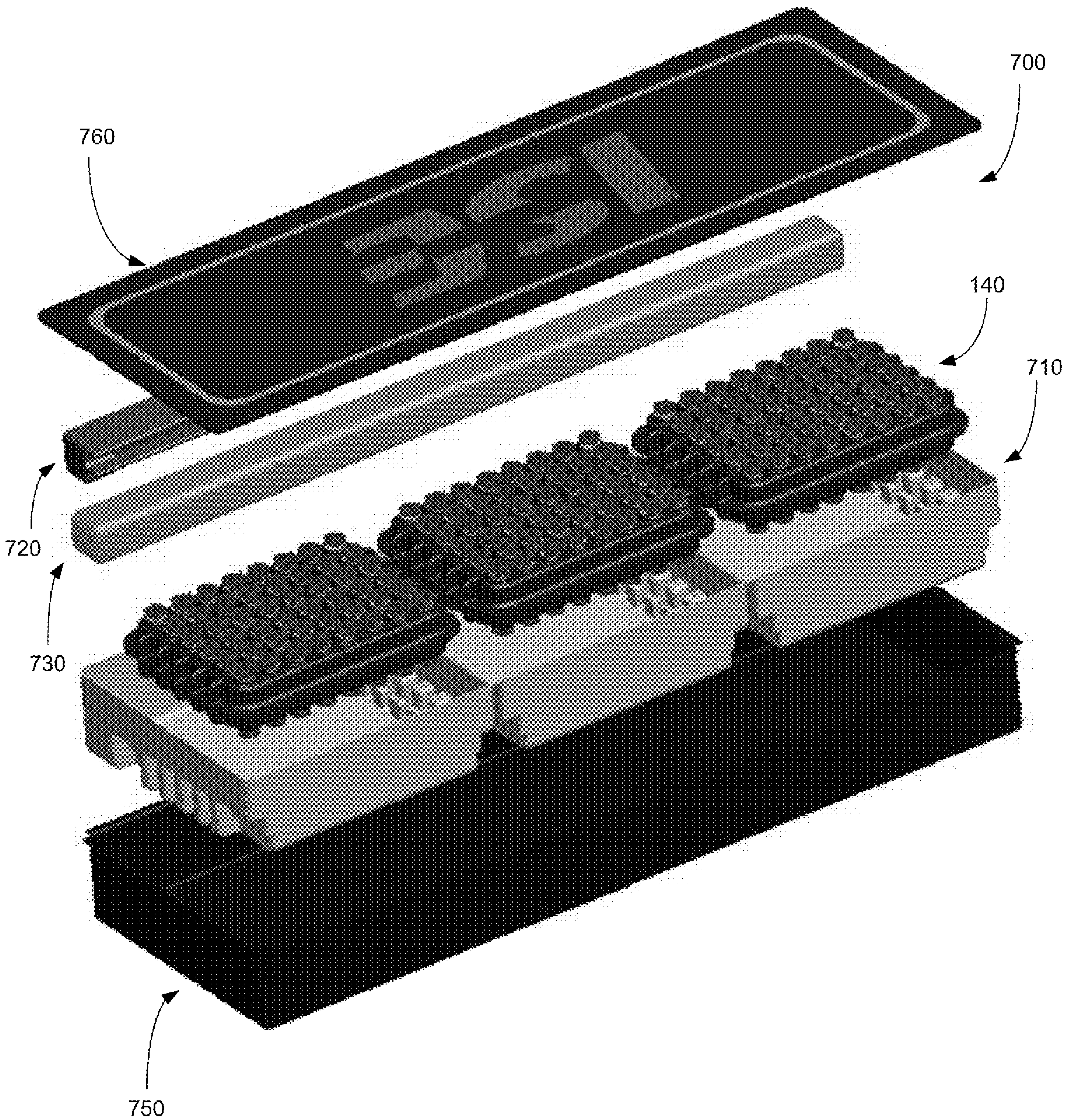


FIG. 13

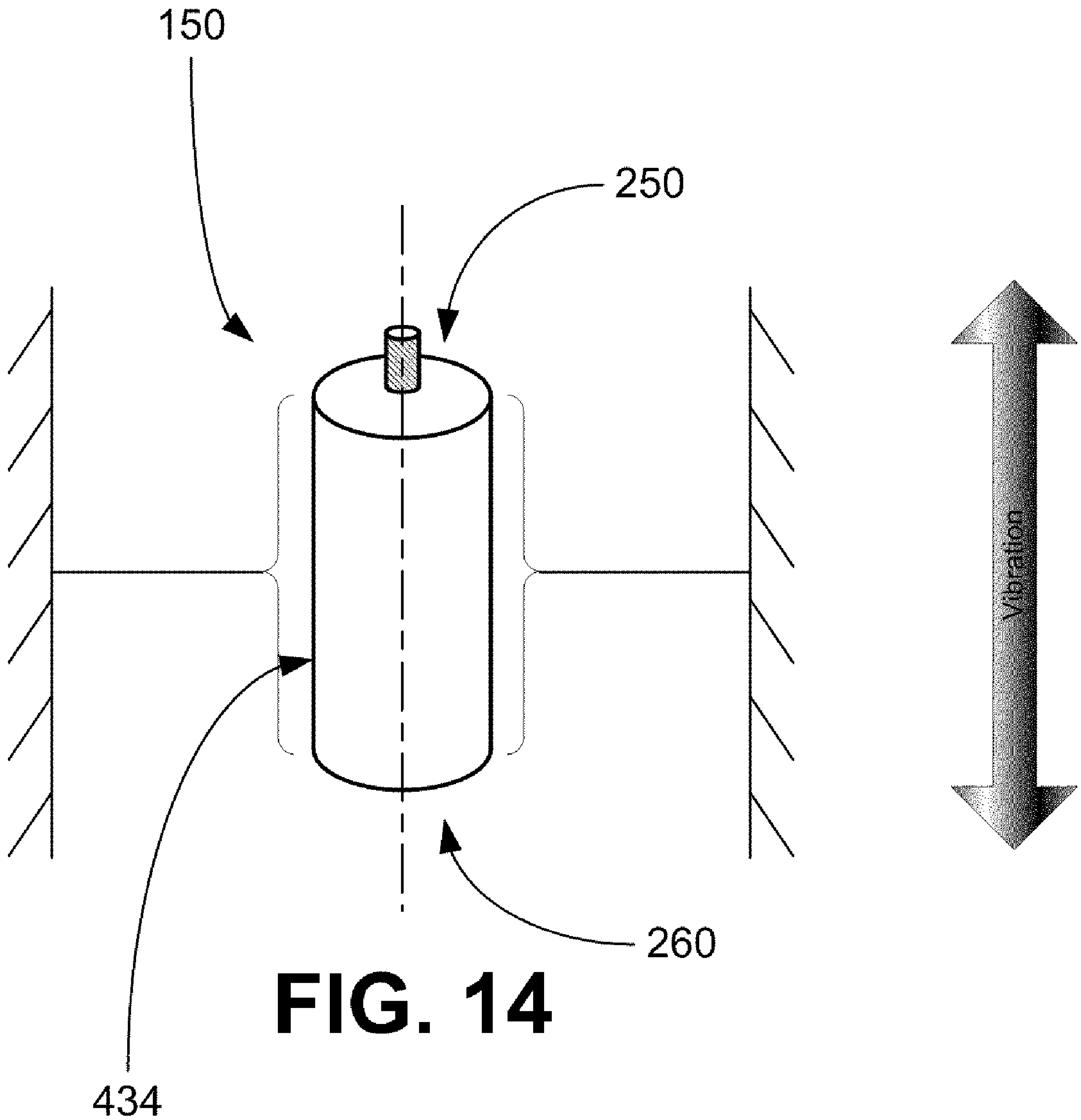


FIG. 14

HYBRID VEHICLE PROPULSION ENERGY STORAGE SYSTEM

RELATED APPLICATIONS

This is a continuation of pending application Ser. No. 12/343,957 filed Dec. 24, 2008, which is a continuation of pending application Ser. No. 12/343,271 filed Dec. 23, 2008. All of these applications are incorporated by reference herein as though set forth in full.

FIELD OF THE INVENTION

The field of the invention generally relates to an energy storage specially adapted for a hybrid electric vehicle. In particular, the invention relates to a high-voltage, high-power ultracapacitor energy storage pack composed of a large number of serially connected individual low-voltage ultracapacitor cells that store propulsion energy.

BACKGROUND OF THE INVENTION

The connecting together of individual battery cells for high-voltage, high-energy applications is well known. However, the chemical reaction that occurs internal to a battery during charging and discharging typically limits deep-cycle battery life to hundreds of charge/discharge cycles. This characteristic means that the battery pack has to be replaced at a high cost one or more times during the life of a hybrid-electric or all-electric vehicle.

Batteries are somewhat power-limited because the chemical reaction therein limits the rate at which batteries can accept energy during charging and supply energy during discharging. In a hybrid-electric vehicle application, the battery power limitation manifests itself as an internal series resistance that restricts the drive system efficiency in capturing braking energy through regeneration and supplying power for acceleration.

Ultracapacitors are attractive because they can be connected together, similar to batteries, for high-voltage applications; have an extended life of hundreds of thousands of charge/discharge cycles; and have a low equivalent internal series resistance that allows an ultracapacitor pack to accept and supply much higher power than similar battery packs. Although ultracapacitor packs may be more expensive than battery packs for the same applications and currently cannot store as much energy as battery packs, ultracapacitor packs are projected to last the life of the vehicle and offer better fuel-efficient operation through braking regeneration energy capture and supplying of vehicle acceleration power. Furthermore, the price of an ultracapacitor pack has the potential to decrease significantly because of economies of scale in known manufacturing techniques.

During charging and discharging operation of the ultracapacitors, parasitic effects, as modeled by the equivalent series resistance, cause the cell temperature to increase. Cooling is required to minimize increased temperature operation that would degrade the energy storage and useful life of each ultracapacitor.

Other than operation/performance, the key consideration for ultracapacitor packs in a heavy duty hybrid-electric vehicle is heat dissipation. The ultracapacitor cells used in ultracapacitor packs are constructed as layered sheets of conductive material and dielectric, wrapped around a central axis and forming a cylinder. Terminals are placed on each end of the cell. The terminals are typically threaded and provide both an electrical coupling point and a support point. The thermal

characteristics of this construction are such that most of heat generated by the cell is transferred to the environment via the two ends of the cell. Currently, heat dissipation is accomplished by blowing cooling air across the cylindrical bodies/cases of the cells.

Ultracapacitor packs in vehicles, especially heavy-duty vehicles, reside in a harsh operating environment and face unique challenges not present in non-vehicular applications. In particular, the vehicular environment is dirty, hot, and subject to vibration. Current implementations attempt to address these problems, but leave room for improvement and innovation.

In heavy-duty transit bus applications and other heavy duty vehicle applications higher performance and smaller size ultracapacitor packs are required, especially where ultracapacitor packs are required to be placed on the roof of the heavy-duty transit bus or other heavy duty vehicle.

SUMMARY OF THE INVENTION

An aspect of the invention involves an energy storage cell pack cradle assembly of an energy storage cell pack including multiple rows of energy storage cells oriented along a dominant axis of vibration, the energy storage cells including an energy storage cell body with a casing, opposite end portions, and respective electrically conductive terminals extending from the end portions. The energy storage cell pack cradle assembly includes a first cradle member including a plurality of energy storage cell body supporting structures including respective holes, a second cradle member including a plurality of energy storage cell body supporting structures including respective holes and one or more fasteners connecting the first cradle member and the second cradle member together. The energy storage cell body supporting structures are configured to structurally support the energy storage cells, with the energy storage cells oriented along a dominant axis of vibration, by the energy storage cell bodies with the respective electrically conductive terminals extending through the respective holes without structural support of the electrically conductive terminals by the cradle members.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and form a part of this specification, illustrate embodiments of the invention and together with the description, serve to explain the principles of this invention.

FIG. **1** is a top plan and perspective views of an embodiment of an ultracapacitor pack system.

FIG. **2** is an exploded perspective view of an embodiment of an ultracapacitor energy storage cell pack of the ultracapacitor pack system illustrated in FIG. **1**.

FIG. **3** is an exploded perspective view of an embodiment of an ultracapacitor pack assembly of the ultracapacitor energy storage cell pack of FIG. **2**.

FIG. **4**A is a perspective view of an upper cradle member of the ultracapacitor pack assembly of FIG. **3**.

FIG. **4**B is a perspective view of a lower cradle member of the ultracapacitor pack assembly of FIG. **3**.

FIG. **5** is a perspective view of an alternative embodiment of an ultracapacitor pack assembly.

FIG. **6**A is a perspective view of the ultracapacitor pack assembly of FIG. **3** after a first step in a method of assembly of the ultracapacitor pack assembly.

FIG. **6**B is a perspective view of the ultracapacitor pack assembly of FIG. **3** after a second step in a method of assembly of the ultracapacitor pack assembly.

FIG. 6C is a perspective view of the ultracapacitor pack assembly of FIG. 3 after a third step in a method of assembly of the ultracapacitor pack assembly.

FIG. 6D is a perspective view of the ultracapacitor pack assembly of FIG. 3 after a fourth step in a method of assembly of the ultracapacitor pack assembly.

FIG. 7 is a perspective view of an alternative embodiment of an ultracapacitor pack assembly.

FIG. 8A is a perspective view of a further embodiment of an ultracapacitor pack assembly.

FIG. 8B is a perspective view of an ultracapacitor and an embodiment of ultracapacitor holders for spacing and securing the ultracapacitors in the ultracapacitor pack assembly of FIG. 8A.

FIG. 9A is a top perspective view of a still further embodiment of an ultracapacitor pack assembly.

FIG. 9B is a bottom perspective view of the ultracapacitor pack assembly of FIG. 9A.

FIG. 10 is a perspective view of an embodiment of terminal heat sinks and an interconnect for a pair of ultracapacitors.

FIG. 11A is a side elevational view of another embodiment of a terminal heat sink being applied to an ultracapacitor.

FIG. 11B is a top plan view of the terminal heat sink of FIG. 11A.

FIG. 11C is a side elevational view of the terminal heat sink of FIG. 11A shown applied to the ultracapacitor.

FIG. 12 is a cross sectional view of an embodiment of an ultracapacitor pack cooling system of the ultracapacitor energy storage cell pack of FIG. 2.

FIG. 13 is a perspective view of an alternative embodiment of an ultracapacitor energy storage.

FIG. 14 is schematic view of an ultracapacitor and shows how the ultracapacitor is supported in an embodiment of the cradle assembly of the ultracapacitor pack assembly.

DETAILED DESCRIPTION OF THE INVENTION

This disclosure of the invention is submitted in furtherance of the constitutional purposes of the U.S. patent Laws "to promote the progress of science and useful arts" (Article 1, Section 8).

With reference to FIG. 1, an ultracapacitor energy storage system **100** constructed in accordance with an embodiment of the invention will be described. The ultracapacitor energy storage system **100** includes a plurality of ultracapacitor energy storage cell packs **110** connected to a central water chiller **120** or cooling supply for cooling ultracapacitors of the ultracapacitor energy storage cell packs **110**, and a controller **130** for controlling cooling of the ultracapacitor energy storage cell packs **110** and/or controlling electrical functions (and/or other functions) of the ultracapacitor energy storage cell packs **110**. As illustrated in this particular embodiment, each ultracapacitor energy storage cell pack **110** here includes 48 (6×8) ultracapacitors oriented so that the longitudinal axis of each ultracapacitor is vertically oriented. This configuration, along with the compact nature of each ultracapacitor energy storage cell pack **110**, provides for low profile, modular ultracapacitor energy storage cell packs **110** that can be arranged in a variety of different configurations and numbers to provide the desired energy storage for the particular application. For example, FIG. 1 shows an exemplary configuration of six ultracapacitor energy storage cell packs **110** for assembly onto a rooftop of a metropolitan transit bus for supplying power to propel the bus. In other applications, different configurations, arrangements/orientations, and/or numbers of ultracapacitor energy storage cell packs **110** may be provided. In alternative embodiments, the inventive principles described herein are applied to batteries in a battery pack or other power supplies in a power supply pack.

FIG. 2 is an exploded perspective view of an embodiment of the ultracapacitor energy storage cell pack **110** of the ultracapacitor energy storage system **100** illustrated in FIG. 1. FIG. 3 is an exploded perspective view of an embodiment of an ultracapacitor pack assembly of the ultracapacitor energy storage cell pack of FIG. 2, further exploding cradle assembly **160**. Here, the exemplary ultracapacitor energy storage cell pack **110** includes an ultracapacitor energy storage cell pack assembly **140** with 48 (6×8) ultracapacitors **150** secured in place relative to each other, housed within, and protected by cradle assembly **160**. In the embodiment shown, the ultracapacitors **150** are Maxwell—Boostcap® Ultracapacitors model BCAP3000, rated at 3000 Farads, 2.7 Volt operating voltage, >1 million duty cycles.

With reference to FIGS. 3 and 10, terminal heat sinks **170**, which are disposed outside of cradle assembly **160** for cooling the ultracapacitors **150** in a manner to be described, are thermally connected to terminals **240** extending from opposite ends **250**, **260** of each ultracapacitor **150**. Interconnects **270** form an electrical bridging device that electrically connects terminals **240** from adjacent ultracapacitors **150** (to connect the ultracapacitors **150** in series).

Referring to FIG. 2, the ultracapacitor energy storage cell pack **110** includes a housing **180** comprised of an upper cover **190** and a lower cover **200**. The housing **180** includes fastener mechanisms for fastening the upper cover **190** to the lower cover **200**. On an interior of the covers **190**, **200** are structural supports for supporting the ultracapacitor energy storage cell pack assembly **140** at attachment/mounting points on the ultracapacitor energy storage cell pack assembly **140**. The attachment/mounting points may be selected such that the pack assembly **140** is oriented in an advantageous orientation. Disposed within one end of the housing **180** is a blower and cooler assembly **210** with a cross flow fan/flow source **220** and a heat exchanger **230**. Although not shown, circuitry may be electrically coupled to the terminals **240** in a well-known manner.

With reference to FIGS. 3, 4A, and 4B, the cradle assembly **160** of the ultracapacitor pack assembly **140** will be described in more detail. As illustrated, the cradle assembly **160** includes a vacuum-formed or pressure-formed plastic upper cradle member **280** and a matching vacuum-formed plastic lower cradle member **290** that form respective upper and lower array support structures for holding the ultracapacitors **150** by opposite end portions of the ultracapacitor cell bodies instead of by their terminals **240**. In the embodiment shown, the cradle members **280**, **290** may be made of a nonconductive material such as FR59 plastic. Each cradle member **280**, **290** includes a peripheral flange **300** with spaced bolt holes **310** therein. The flange **300** surrounds a central recessed/raised section **320** (i.e. recessed on an inner surface **350**/raised on an outer surface **360**). Circular slots **330** are disposed in a wall/partition **340** of each cradle member **280**, **290** to provide a terminal interface allowing the ultracapacitor terminals to pass through. Each slot **330** includes a recessed annular wall **330** that projects outwardly from outer surface **360**. The annular wall **330** has a diameter slightly smaller than an exterior diameter of the ultracapacitor **150** for securably receiving (i.e., to provide spring force and/or grip on) the end portions **250**, **260** of the ultracapacitor **150**. In certain applications, the cradle assembly **160** may be further configured to direct air flow across the terminals. For example, the cradle assembly **160** may include vanes and/or form ducting such that air/coolant does not bleed out of the desired flow path, such that additional coolant is directed toward "hot spots" on the pack, such that back pressure on the flow source is reduced, etc.

One of the many advantages of the cradle assembly **160** is that it enables the ultracapacitors **150** to be placed closer together than was possible in the past, making for a more compact ultracapacitor pack assembly **140**. To this end, the slots **330** are disposed very close to one another. An additional advantage of disposing the slots **330** so close together is that the annular walls **330** are disposed close enough together so that the plastic material that forms structural support for one annular wall **330** adds to the structural support and rigidity of an adjacent annular wall **330**. This increases the structural support provided by the slots/cups **330**, increasing the structural support of the cradle assembly **160** (i.e., the plastic material forming the annular walls **330** doubles in on itself to form the additional structural support.

The annular wall **330** terminates at a proximal end in the wall/partition **340** and terminates at a distal end in annular flange **380**. Annular flange **380** extends radially inwardly from the annular wall **330** and includes a central hole **390** with a diameter larger than an outer diameter of the terminal **240** (so the terminal **240** can pass there through) and smaller than the outer diameter of the ultracapacitor **150** so that the end portions **250**, **260** of the ultracapacitor **150** abut the annular flange **380** while the terminal **240** passes through the hole **390**. Thus, the circular slots **330** form cups for securably receiving end portions **250**, **260** of the ultracapacitors **150**.

Preferably the ultracapacitors **150** are oriented along the dominant axis of vibration (See FIG. **14**), which is typically vertically, as shown, for vehicle applications. The ultracapacitors **150** are supported by their cylindrical body/case **434** and end portions/caps **250**, **260** rather than by their terminals **240**.

With reference to FIG. **5**, an alternative embodiment of a cradle assembly **400** is shown. The cradle assembly **400** is similar to the cradle assembly **160** described above except that the cradle assembly **400** includes leg stands **410** for supporting the cradle assembly **400** in the housing **180**. In further embodiments, the cradle assembly **160**, **400** includes additional or fewer features, such as, but not by way of limitation added stiffening ribs (e.g., integrally formed with the cradle members **280**, **290**) or separate stiffeners (not shown) added between rows/columns of ultracapacitors **150** to add structure in the cradle members **280**, **290** or a smaller flange **300** (or no flange **300**).

In an alternative embodiment, the ultracapacitors **150** are laterally supported or slid into a middle support structure between the cradle members **280**, **290** (or other top/bottom support plates/structures). The middle support structure may be used for fire suppression, stress relief for the cradle assembly, vibration dampening, additional structure, and/or stability.

With reference to FIGS. **2**, **6**A-**6**D, and **10**, an exemplary method of assembly of the ultracapacitor pack assembly **140** will be described. First, with reference to FIG. **6**A, the ultracapacitors **150** are assembled into the slots/cups **330** of the lower cradle member **290** so that lower end portions **260** of the ultracapacitors **150** rest on the annular flange **380** while the terminals **240** pass through the holes **390**. Second, the upper cradle member **280** is assembled onto the ultracapacitors **150** so that top end portions **250** of the ultracapacitors **150** rest on the annular flange **380** while the terminals **240** pass through the holes **390** (i.e., top end portions **250** are assembled into the slots/cups **330**). Third, the interconnects **270** are assembled so as to electrically connect terminals **240** from adjacent ultracapacitors **150** (to connect the ultracapacitors **150** in series). Fourth, the terminal heat sinks **170** are fastened to the terminals **240**. Fasteners (e.g., bolts/nuts) are used to connect the flanges **300** of the cradle members **280**, **290** together and the ultracapacitor pack assembly **140** is inserted into the lower cover **200**. The cradle members **280**, **290** generally enclose and protect the ultracapacitors **150** so that the ultracapacitor pack assembly **140** forms a module. The ultracapacitor pack assembly **140** may be supported in the ultracapacitor energy storage cell pack **110** by the flanges **300**. The other components and/or circuitry of the ultracapacitor energy storage cell pack **110** may be installed into the lower cover **200** before, during, or after the ultracapacitor pack assembly **140** is assembled and inserted into the ultracapacitor energy storage cell pack **110**.

The ultracapacitor pack assembly **140** is advantageous because it is quick, easy, and inexpensive to assemble/manufacture, includes fewer components that ultracapacitor pack assemblies in the past, relieves the terminals **240** from supporting the ultracapacitors **150**, is vibration resistant, forms a streamlined, compact ultracapacitor pack assembly, offers excellent high voltage isolation protection, provides robust environmental protection of components, particularly the ultracapacitors **150**, for heavy duty applications, and provides excellent thermal insulation to reduce system heat rejection requirements. Its modularity gives vehicle manufacturers and integrators flexibility in configuring the energy storage on the vehicle. In addition, it provides for a single, uniform module that can be used in varying numbers to meet diverse energy storage requirements.

As illustrated in FIG. **14**, the ultracapacitors **150** are disposed/supported with their longitudinal axis vertically oriented. End portions **250**, **260** and body **434** of the ultracapacitors **150**, as opposed to the terminals **240**, are structurally supported in the slots **330** of the cradle members **280**, **290**, protecting the structural integrity of the ultracapacitors **150** and preventing damage to the terminals **240** or damage to the ultracapacitors **150** from being structurally supported by the terminals **240**. Vibration during vehicle travel is often in a vertical (up and down) direction as shown. Structurally supporting the end portions **250**, **260** and the body **434** of the ultracapacitors **150**, with the ultracapacitors **150** vertically oriented as shown, protects the structural integrity of the ultracapacitors **150** during vibration of the ultracapacitor pack assembly **140** and vehicle. The cradle members **280**, **290** combine to form a protective, sealed, enclosed housing/cover/box for the ultracapacitors **150**, protecting the ultracapacitors **150** from dirt, dust, debris, water, and other contamination.

With reference to FIG. **7**, an alternative embodiment of an ultracapacitor pack assembly **420** will be described. Similar to cradle assembly **160**, the ultracapacitors **150** are supported by the opposing end portions **250**, **260** of their casings, however, rather than wrapping down the sides of the array of ultracapacitors **150** and coupling to each other, the supporting members are kept apart and do not generally enclose the ultracapacitors **150**. Instead, the upper and lower supporting members are coupled to each other via an intermediate member. In this way access is provided to the center area of the ultracapacitors **150** between their terminals **240**. This may be beneficial for routing electronic circuitry (e.g., monitoring, balancing, and protection circuitry). Also, this may provide a supplemental cooling path to cool the ultracapacitor bodies **434** in addition to their terminals **240**. For example, as illustrated in FIG. **7**, the ultracapacitor pack assembly **420** includes an upper support board (e.g., FR4 board) **430** and a lower support board **440** with holes therein to receive end portions of ultracapacitors **150**. As above, the ultracapacitors

150 are oriented along the dominant axis of vibration (See FIG. 14), which is typically vertically, as shown, for vehicle applications. Similarly, the ultracapacitors 150 are supported by their cylindrical body/case 434 rather than by their terminals 240. Vertical support members/posts 450 couple and support the support boards 430, 440 and rest of the ultracapacitor pack assembly 420 with reference to each other and to the housing 180. Plastic brackets 460 are inexpensively disposed on outer surfaces of the support boards 430, 440 for retaining the end portions of the ultracapacitors 150 in the Z-direction relative to the support boards 430, 440. Plastic blind rivets/plastic split shanks 470 are used to fasten the plastic brackets 460 to the supports 430, 440 via holes in the support boards 430, 440. It is understood that other means may be used to secure the ultracapacitor in the vertical direction. For example, upper and lower support boards may integrate a cup interface to receive and restrain the end portions 250, 260 of ultracapacitor 150. Likewise a ring section of a second board may be attached to support boards 430, 440 wherein its inner diameter is larger than the terminal but smaller than the end portion of the ultracapacitor cell, and the diameter of boards 430, 440 are approximately the same as that of the cell.

With reference to FIGS. 8A and 8B, a further embodiment of an ultracapacitor pack assembly 471 will be described. Here, a different approach is taken. Ultracapacitors 150 are equipped with adaptors or holders that transfer support loading to their end portions 250, 260. In addition, the adaptors/holders 475 extend the interface with the ultracapacitor to provide a flow path for a coolant to convect heat. For example, as illustrated, the ultracapacitor pack assembly 471 includes an upper support plate (e.g., ABS/PVC plate) 472 and a lower support plate 473 with sets of support holes or slots on inner surfaces of the plates 472, 473 to receive spacer supports or support pegs 474 (FIG. 8B) of ultracapacitor holders 475. As above, the ultracapacitors 150 are preferably oriented along the dominant axis of vibration (See FIG. 14), which is typically vertically, as shown, for vehicle applications. Vertical support posts 476 couple and support the support plates 472, 473 and rest of the ultracapacitor pack assembly 471.

The ultracapacitor holders 475 function as extension devices, one for each end of the ultracapacitor 150. Moreover, the ultracapacitors 150 are supported by their cylindrical body/case 434 rather than by their terminals 240. As illustrated, the ultracapacitor holders 475 include annular cuffs 477 that are akin to cup holders and slidably receive end portions of the ultracapacitors 150. The support pegs 474 extend from the annular cuff 477 and are circumferentially spaced along the annular cuff 477. When assembled as shown in FIG. 8A, the ultracapacitor holders 475 perform the following functions: (1) space the ends of the ultracapacitors 150 from the inner surfaces of the support plates 472, 473; (2) provide a passage for coolant (e.g., cooled air flow) to pass over the terminal heat sinks 170 for cooling the ultracapacitors 150; and (3) provide an interface with the support plates 472, 473.

Preferably, the ultracapacitor holders 475 and the support plates 472, 473 are interfaced so that the ultracapacitor holders 475 can not rotate, translate, or pass through the support plates 472, 473. In this way coolant flow can be better controlled in a predictably way. Once the ultracapacitors 150 are positioned, the support plates 472, 473 are fastened together, thus holding the ultracapacitors 150 by their cylindrical bodies/cases 434 only. The unified structure can then be supported by a housing of the ultracapacitor pack assembly 471. This embodiment lends itself well to low cost mass production wherein the uniform end holders are placed on both ends of the ultracapacitors 150 and inserted into machined slots in the support plates. Preferably, the machined slots are keyed such that the resultant flow path is made in an optimal predetermined manner.

With reference to FIGS. 9A and 9B, a still further embodiment of an ultracapacitor pack assembly 500 will be described. Here, the ultracapacitor casings are supported both laterally and at their end portions, For example, as illustrated, the ultracapacitor pack assembly 500 includes a support matrix 510 (e.g., a foam or polymer core) with cylindrical holes therein having a diameter similar to the external diameter of the ultracapacitors 150 for slidably receiving/supporting the ultracapacitors 150 therein. In addition, the support matrix 510 may have plastic dividers or other support members disposed therein (e.g., elongated, thin plastic support dividers disposed between rows and/or columns of ultracapacitors 150) for adding structural support to the foam core support matrix 510 for example. Preferably, the ultracapacitors 150 are oriented along the dominant axis of vibration (See FIG. 14), which is typically vertically, as shown, for vehicle applications.

The ultracapacitors 150 are supported by their cylindrical body/case 434 rather than by their terminals 240. In particular, the ultracapacitors 150 may be held in position by friction force applied to the external surface/sides of the cylindrical body/case 434. For example, where multiple ultracapacitors 150 are supported, the ultracapacitors 150 may be held by a pressure-fit within a supporting structure (e.g., a foam core support matrix 510, a grid support structure having a friction interface (not shown), etc.). In the embodiment shown, the cylindrical holes of the support matrix 510 are slightly smaller than the external diameter of the ultracapacitors 150; the ultracapacitors 150 may be supported primarily laterally by their casings.

Alternately, the ultracapacitors 150 may be positioned and held in place by injecting foam (or other setting material) between the ultracapacitors 150 and a supporting structure. Preferably, the multiple ultracapacitors 150 are positioned in a structural grid, and then the filler material is applied. In this way, individual ultracapacitors 150 may be removed without disturbing the balance of the array. In an alternative embodiment, the structural grid may be supported by a housing of the entire energy storage pack. Alternately, when using the structural grid, the filler material may be a non-expanding friction material (e.g., rubber, epoxy, etc.) that is fixed to the grid and holds the canister in place.

Alternately, where the diameter of the cylindrical holes of the support matrix 510 are slightly larger than the external diameter of the ultracapacitors 150, the ultracapacitors 150 may be supported primarily by their end portions via end brackets fixed to the support matrix 510. For example, as illustrated and similar to FIG. 7 discussed above, plastic end brackets 530 are fastened on the lower surface of the foam core support matrix 510 for retaining the end portions of the ultracapacitors 150 in the Z direction relative to the support matrix 510.

In this and the abovementioned embodiments, support matrix 510, the filler material, and/or the grid are preferably made from a flame resistant material. Similarly, here and above, vertical support posts 520 may be used to support the support matrix 510 within the rest of the ultracapacitor pack assembly 500.

With reference to FIG. 10, the interconnects 270 and the terminal heat sinks 170 will now be described in greater detail in turn below. Each interconnect 270 forms a conductive path between the terminals 240 of two ultracapacitor cells 150. In this way multiple cells can be electrically coupled in series, thus aggregating the total voltage of the cell to a level suitable for hybrid-electric propulsion applications. For example, as illustrated here interconnect **270** may be made from a solid stamped piece of aluminum including a pair of flat terminal receivers **540** with holes **542** therein to receive the terminals **240** of the ultracapacitors **150**. Additionally, interconnect **270** may include an access point for cell control and monitoring. In particular, extending upward from the flat bridge section **554** is a terminal **560** (e.g., for connecting monitoring or control circuitry such as balancing resistor(s), control circuit, etc.). Being primarily an electrical bridging device, it is preferable that interconnect **270** be sufficiently flexible so as not to induce stresses in the terminals in excess of its tolerance upon installation. For example, the flat terminal receivers **540** include a bridge **550**, which may be flexible (e.g., thinner material used in bridge **550** and/or multiple preformed bends may be used to make this section flexible), having opposite upwardly angled sections **552** extending upwardly and inwardly from the flat terminal receivers **540**. The opposite upwardly angled sections **552** are joined by a flat bridge section **554**.

Each terminal heat sink **170** forms a thermally conductive path away from the terminal **240** of ultracapacitor cell **150** that it is mechanically coupled to. In particular, terminal heat sink **170** axially transfers heat more efficiently through the ultracapacitor terminals, instead of radially across the internal dielectric layers and through the canister walls. Further terminal heat sink **170** may include a heat exchanger having a thermal performance sufficiently high that the terminal heat sink **170** provides at least half of the required cooling of the ultracapacitor cell **150**. Preferably, terminal heat sink **170** will be made of a material similar to that of the cell terminals. For example, since ultracapacitor terminals are often made of aluminum, terminal heat sink **170** could also be made of aluminum. There are several benefits of using the terminal heat sink **170** as disclosed herein. For example, while some heat exchange takes place via interconnect **270**, the incorporation of cooling surfaces (e.g., fins) would tend to stiffen the interconnect and induce stress in the terminals. In addition, the omnidirectional orientation of terminal heat sink **170**, as illustrated, provides for a single component/device for use on each cell, independent of the cell's orientation in the series string and further provides for simple installation.

The thermal performance required of terminal heat sink **170** will vary according to each application. In particular, it may vary depending on parameters such as the performance desired of the cell, the convection mode and media, the flow rate of the convection media, the thermal gradient between the cell and coolant, etc. Once the parameters are known, the systemic heat transfer coefficient and terminal heat sink thermal performance may be determined as a result of a standard computational fluid dynamics (CFD) analysis. By cooling axially at the terminals, the cells may be cooled much more efficiently and/or the cells may have higher performance, making the energy storage better suited for hybrid-electric propulsion applications.

As illustrated in FIG. **10**, the terminal heat sink **170** forms an energy storage cell terminal cooler/exchanger, or a device that radiates heat from an individual terminal **240**. The terminal heat sink **170** couples to the terminal **240** and provides a heat exchange surface to the surrounding environment. In the embodiment shown, the cooling fins **580** form a convective heat exchange surface in an air flow path. The heat exchange surface may be integrated into a fastener for the terminal **240** (e.g., a threaded nut **570**). Accordingly, the terminal heat sink **170** may both couple items to the ultracapacitor **150** terminal as needed and cool the terminal end of the ultracapacitor **150** at the same time. In another embodiment, the terminal heat sink **170** is configured to bolt a busbar (or other terminal-to-terminal interconnector/electrical bridging device) to the ultracapacitor **150**. According to another embodiment, the terminal heat sink **170** may be configured to provide lateral support (i.e., along the longitudinal axis of the ultracapacitor **150**) so as to support the ultracapacitor **150** within a housing or enclosure. By providing more efficient cooling and moving the heat exchange location away from the canister walls, the terminal heat sinks **170** enable the ultracapacitors **150** to be packed more closely to each other so that cooling air is primarily passed across the terminal ends. By doing so, there is less need for a large cooling air/heat exchange path between the ultracapacitors **150**.

According to one exemplary construction, and as illustrated in FIG. **10**, each terminal heat sink **170** includes a nut **570** with a threaded interior for threadably receiving externally threaded terminal **240** (see also, FIG. **11**C ref. **620**). The nut **570** is welded to a cylindrical tube (not shown). The nut **570** and/or the tube form a receiving section for structurally receiving externally threaded terminal **240**. Annular washers or cooling fins **580** circumferentially surround and extend radially from the cylindrical tube. A top of the terminal heat sinks **170** may include a rotate engagement mechanism/recessed tool interface **590** for rotatable engagement by/with a rotatable tool for screwing the terminal heat sink **170** on/off the externally threaded terminal **240**. In the embodiment shown, the rotate engagement mechanism **590** includes a "key" interface; particularly, three geometrically spaced cylindrical female sections (e.g. bores) for receiving three corresponding male members of a rotatable tool for screwing the terminal heat sink **170** on/off the externally threaded terminal **240**. Thus a key is required to remove the terminal heat sink **170**, providing added security against unauthorized disassembly. In alternative embodiments, the rotate engagement mechanism **590** may include other configurations/structures (e.g., screwdriver slot, Allen stock recess) for rotatable engagement by/with a rotatable tool. The rotate engagement mechanism **590** is also important for controlling the amount of torque applied to the threaded terminal **240** so that the terminals **240** and ultracapacitors **150** are not damaged by applying too much torque. The rotate engagement mechanism **590** is preferably recessed in the top/exposed end of the terminal heat sink **170** since it is preferable that whatever rotatable tool is used to screw/unscrew the terminal heat sink **170** comes in from the top/exposed portion of the threaded terminals **240**.

With reference to FIG. **11**A-**11**C, an alternative construction of a terminal heat sink **610** will be described. The terminal heat sink **610** is generally similar to the terminal heat sink **170** described above except that the terminal heat sink **610** includes an interiorly threaded nut **620** disposed above the cooling fins **580** instead of below the cooling fins **580** as with the heat sink **170** of FIG. **10**. Annular washers or cooling fins **580** circumferentially surround and extend radially from cylindrical tube **630**. Cylindrical tube **630** may be smooth or internally threaded. In the terminal heat sink **610**, the nut **620** is a standard hexagonal nut. The standard hexagonal outer surface of the nut **620** forms a rotate engagement mechanism for rotatable engagement by/with a rotatable tool (e.g., wrench) for screwing the terminal heat sink **610** on/off the externally threaded terminal **240**.

As shown in FIG. **11**C and discussed above, heat radiates in a longitudinal axial direction outwards, towards the terminals **240**, in the direction of the arrows shown. The heat is transferred to the terminals **240**, and from the terminals **240**, through the nut **620**/tube **630** and to the cooling fins **580**.

Convective cooling air flows past the cooling fins **580** to transfer heat therefrom to cool the ultracapacitor **150**.

According to one exemplary construction, the terminal heat sink **610** may be simply, quickly, and easily manufactured by sliding L-type annular washer(s) **580** along the outside of the tube **630** into desired positions and enlarging the outer diameter of the tube **630** relative to an inner diameter of annular L-type washers (e.g., by forcing a ball bearing having a larger diameter than an inner diameter of the tube **630** through the tube **630**) so that the washers are fixed to the tube **630**. Alternatively, the washer(s) **580** may then be welded (or otherwise fixed) to the end of the tube **630**. Alternatively, terminal heat sink **610** is manufactured by sliding L-type annular washers along the outside of the tube **630** into desired positions and fixing the inner annular portion of annular L-type washers to the outer circumference of the tube **630** and fixing the nut **620** to end of the tube **630**. Fixing the components together may be performed by brazing, welding, and/or other fixing techniques.

In alternative embodiments of the terminal heat sink **170**, **610**, the number and/or configuration(s) of the heat fins **580** may vary/differ from that shown. For example, but not by way of limitation, in one or more embodiments, terminal heat sink **170**, **610** includes one or more of the following features, the terminal heat sink **170**, **610** radiates outwardly in a symmetric configuration from the receiving section, the symmetric configuration is annular, and/or the symmetric configuration is at least one of curvilinear (e.g., circular, annular, oval) and rectilinear (e.g., square, rectangular, rhomboid, parallelogram). However the fins are preferably circular, in this way the terminal heat sink **170**, **610** provides omnidirectional cooling and may be installed in any direction, thus making installation quicker. Also, the dimensions of the heat fins **580** are preferably less than the diameter/dimensions of the ultracapacitors **150**. For example, but not by way of limitation, the outer diameter of the heat fins **580** is less than the outer diameter of the ultracapacitor **150**. This minimizes the separation of adjacent cells and interaction between adjacent terminal heat sinks **170**, **610**. Additionally, the first fin (closest to the ultracapacitor **150** end may be in direct contact with the end of the cell for increased heat transfer, or alternately may stand off the end of the cell for increased coolant flow and convection.

The terminal heat sink **170**, **610** is advantageous because, but not by way of limitation, it extracts heat from the ultracapacitor cell in a thermally efficient manner and without the need for a high flow cooling system. The terminal heat sink **170**, **610** provides a low-cost, simple solution for transferring heat from the ultracapacitors **150**. The terminal heat sink **170**, **610** provides cooling for individual ultracapacitors **150**, and provides maximum cooling at the points (i.e., terminal ends) of highest heat. The terminal heat sink **170**, **610** also allows for a more compact form factor in the ultracapacitor pack assembly because the ultracapacitors **150** can be placed closer together since cooling occurs at the terminals **240** and not at the cylindrical body/case **434**. Similarly, since the cells are cooled more efficiently, less cooling air is required and consequently much less energy is required to perform the same cooling.

With reference to FIG. **12**, an embodiment of ultracapacitor pack cooling system **650** for the ultracapacitor energy storage cell pack **140** will be described. Preferably, ultracapacitor pack cooling system **650** is a closed loop system. In this way, external contaminates commonly found in hybrid vehicles are excluded from the energy storage, thus extending its life and reliability. The ultracapacitor pack cooling system **650** includes the blower and cooler assembly **210** disposed within one end of the housing **180**. The blower and cooler assembly **210** includes the cross flow fan/flow source **220** and the heat exchanger **230**. The cross flow fan/flow source **220** and the heat exchanger **230** are laterally elongated and extend substantially the entire lateral length of the ultracapacitor energy storage cell pack **140**. In other words, the width of the cross flow fan/flow source **220** and the heat exchanger **230** is substantially the same width of each row (e.g., 6 rows shown in embodiment of FIG. **2**). Of course, cross flow fan/flow source **220** may be a fan extending the length of first row **692** of ultracapacitors **150**, or it may include the combination of a smaller fan and ducting or vanes distributing the flow to first row **692** of ultracapacitors **150**. Preferably, a, front portion of the cross flow fan/flow source **220** includes upper guide **660** and lower guide **670** that form a shroud for directing air flow from the cross flow fan/flow source **220** in the manner shown in FIG. **12** and minimizes leakage.

Coolant flow or a coolant flow path **680** flows over and through the upper terminal heat sinks **170**, causing convective cooling of the cooling fins **580** (transferring heat from the upper terminals **240**) to cool the ultracapacitors **150**. Air flows around an opposite end of the ultracapacitor energy storage cell pack **140** and back to the heat exchanger **230** via a return flow or return flow path **690**. Similar to the convective cooling that occurs in the coolant flow path **680**, the return flow **690** flows over and through the lower terminal heat sinks **170**, causing convective cooling of the cooling fins **580** (transferring heat from the lower terminals **240**) to cool the ultracapacitors **150**. Generally, air flow will be substantially or completely blocked from crossing/bleeding over the side of the ultracapacitor energy storage cell pack **140**. This may be accomplished with dedicated ducting/blockage/sealants and/or configuring structures such as the housing **180** or cradle assembly **160** to perform this task

According to the illustrated embodiment, the temperature of the return flow **690** is higher than the temperature of the coolant flow path **680** because the return flow **690** includes the heat removed from upstream flow across the terminal heat sinks **170**. Thus, the temperature gradient associated with the air flow above the first row **692** of ultracapacitors **150** is the highest and the temperature gradient associated with the air flow below the first row **692** of ultracapacitors **150** is the lowest. Since, heat transfer occurs in a longitudinal axial direction outwards, towards the terminals **240**, in the direction of the arrows shown in FIG. **11**C, and in light of the varying temperature gradients, the first row of cells may experience greater cooling at the top terminal than at the bottom terminal, whereas the last row of cells may experience a more even cooling at the top and bottom terminals. However, the average temperature of the air flow above and below each row of ultracapacitors **150** is the same for every row (i.e., every row has the same average temperature). As a result, each row of ultracapacitors **150** (as well as all ultracapacitors **150**) are cooled the same.

The heat exchanger **230** removes the added heat from the return flow **690** from the energy storage cell pack **110**. Heat exchanger **230** may utilize an external cooling supply as well. For example, preferably heat exchanger **230** will be integrated in a vehicle cooling system. In particular, a coolant will pass through the energy storage cell pack **110** extracting heat from the hotter air flow. This may be accomplished by passing the coolant through a finned tube and passing the heated air flow across it. With reference additionally to FIG. **1**, the heat exchanger **230** from each ultracapacitor energy storage cell pack **110** may be connected to a central water chiller or cooling supply **120** for transferring coolant through the heat exchangers **230** for removing heat from the ultracapacitor energy storage cell packs **110**. The flowing coolant takes heat from the ultracapacitors **150**, and the heat in the coolant is removed with the heat exchanger **230**. The controller **130** may control cooling of the ultracapacitor energy storage cell packs **110** measuring the temperature of the packs and metering the coolant flow and/or temperature. Additionally, the heat exchanger **230** may be located external to the housing; however the cooling air of the pack is preferably part of a closed-loop system.

According to the preferred embodiment shown, both the cross flow fan/flow source **220** and the heat exchanger **230** are integrated into the ultracapacitor energy storage cell pack **110**. Preferably, the heat exchanger **230** is cooled externally using coolant from either the vehicle cooling system (not shown) or a central water chiller or cooling supply **120** (FIG. **1**). In an alternative embodiment, one or both of the cross flow fan/flow source **220** the heat exchanger **230** are not integrated into the ultracapacitor energy storage cell pack **110**.

According to the embodiment shown, the ultracapacitors **150** are vertically arranged in a single-level array, and the coolant (e.g., air) will pass over the top (and/or or bottom) of the ultracapacitors **150**, wrap around, and enter the heat exchanger **230** to extract heat. The terminal heat sinks **170** on the terminals **240** form mini heat exchangers (e.g., finned nuts) so as to improve the transfer of heat from the terminals **240** to the coolant. This design is particularly good with ultracapacitors **150** because the internal construction of the ultracapacitors **150** makes it far more efficient to extract heat from the terminals **240** rather than the cases/cylindrical body **434** of the ultracapacitors **150**. This is true even though there is much more surface area around the external surface of the cases/cylindrical body **434** than the external surface of the terminal **240**, making this cooling approach counterintuitive, especially since one would think that enclosing the hot ultracapacitors **150** in a sealed, enclosed box would raise the temperature of the ultracapacitors **150**. As shown in FIG. **11**C, heat radiates in a longitudinal axial direction outwards, towards the terminals **240**, in the direction of the arrows shown. The heat is transferred to the terminals **240**, and from the terminals **240**, through the tube **630** and to the cooling fins **580**. According to one embodiment, as shown in FIG. **12**, the cooling air is propelled by cross flow fan **220** in a linear, uniform flow across the terminal heat sinks **170**. This cross flow fan (also called a tangential flow fan) provides for uniform and predictable heat transfer. As illustrated, the cross flow fan **220** efficiently redirects the air flow from the integrated heat exchanger **230** back over the terminal heat sinks **170**, thus closing the ultracapacitor cooling loop. The cross flow fan **220** spans the long profiles associated with the cell array in the most efficient manner (compared to, for example, axial fans and centrifugal fans, which may require multiple motors and add bulk to the housing, based on their principles of operation). The above closed-loop cooling strategy/system provides active cooling, allowing operation of the ultracapacitor pack in all climates, and provides consistent cell-to-cell temperature control as compared to open loop systems that may vary depending on ambient conditions.

As used in a hybrid electric vehicle, some of the characteristics of the ultracapacitor energy storage cell pack **110** may include a rated voltage of 2.3×48=110.4 V, a recommended max voltage of 2.5×48=120 V, a surge voltage of 2.7×48=129.6 V, an isolation voltage of 2500 V, a rated continuous current of 150 A (peak of 300 A), a leakage current of <5 mA, a number of 48 cells (each rated at 3000 F) in the module, a lifetime of 40000 hrs (based on a continuous 33 kW cycle), 1 million Cycles (50% DoD), capacitance of 62.5 F, total energy stored nominal of 105.8 Wh (2.3 V/cell), total energy stored peak of 125 Wh (2.5 V/cell), DC ESR of 16.5 mOhms, heat rejection of 3 kW, cooling water of 30-35 degrees C. at 10 gpm (plumbed in parallel), a storage temperature of −40 degrees C. to 70 degrees C., an operating ambient temperature of −40 degrees C. to 50 degrees C., and a vibration meeting SAE J2380 & J244, an IP rating of IP67, an IEC rating of iec 529 (Type 5), a height dimension of no more than 13 in., a length dimension of no more than 15 in., and a width dimension of no more than 17 in., and a total dimension/volume that does not exceed 13 in.×15 in.×17 in. In addition, while there is no maximum limit to the spacing between the ultracapacitors, preferably there should be no more that 0.25 in.−0.50 in. between the casings of the cells.

Some of the characteristics of the ultracapacitor pack system **100** include a supply voltage of 230 VAC, a rated voltage of 110.4×6=662 V, a recommended max voltage of 120×6=720 V, a surge voltage of 129.6×6=777 V, an isolation voltage of 2500 V, a rated continuous current of 150 A, a rated peak current of 300 A, a leakage current of <5 mA, a number of modules/ultracapacitor energy storage cell packs **110** of 6 modules in the ultracapacitor pack system **100**, a lifetime of 40000 hrs (based on a continuous 33 kW cycle), 1 million Cycles (50% DoD), capacitance of 10.4 F, total energy stored nominal of 634 Wh (2.3 V/cell), total energy stored peak of 750 Wh (2.5 V/cell), DC ESR of 98 mOhms, heat rejection of 3 kW (10236 BTU/hr), cooling water of 30-35 degrees C. at 10 gpm (0.758 L/s), a storage temperature of −40 degrees C. to 70 degrees C., an operating ambient temperature of −40 degrees C. to 50 degrees C., a maximum ambient temperature range inlet of 60 degrees C., vibration meeting SAE J2380 & J244, 144 temperature sensors, an IP rating of IP67, an IEC rating of iec 529 (Type 5), a Beginning of Life (BOL) power loss of no more than 2251 W, and an End of Life (EOL) power loss of no more than 2701 W.

The ultracapacitor pack system **100** preferably includes ground fault circuit protection, a CAN vehicle interface, contactor protection hardware/software, microprocessor controlled cell equalization and monitoring, integral DC Bus precharge resistor(s), fast-acting fuse that reduces damage to DC bus components in event of a short circuit, diagnostic and prognostic functions to predict faults before they occur, and a monitoring system that monitors the voltage and temperature of every capacitor **150** to eliminate hidden cell failures.

With reference to FIG. **13**, an alternative embodiment of an ultracapacitor energy storage cell pack **700** will be described. The ultracapacitor energy storage cell pack **700** is generally similar to the ultracapacitor energy storage cell pack **110** of FIG. **2**, except instead of the ultracapacitor energy storage cell pack **110** including a single ultracapacitor energy storage cell pack assembly **140**, the ultracapacitor energy storage cell pack **700** includes more than one (e.g., 3) ultracapacitor energy storage cell pack assembly **140** disposed in respective inner thermoform liners **710** designed to readily receive all the components (e.g., ultracapacitor pack assemblies **140**) of the ultracapacitor energy storage cell pack **700** for quick, inexpensive, and easy assembly. A single elongated cross-flow fan **720** and a single heat exchanger **730** are used to cool the multiple ultracapacitor energy storage cell pack assemblies **140**. The single elongated cross-flow fan **720**, the single heat exchanger **730**, and the multiple ultracapacitor energy storage cell pack assemblies **140**/inner thermoform liners **710** are disposed within a housing including a lower cover or sheet metal casing **750** and an upper cover or top **760**. The single heat exchanger may supply its own cooling or may be connected to a central water chiller or cooling supply **120** as described above for transferring coolant through heat exchanger(s) **730** for removing heat from one or more ultracapacitor energy storage cell packs **700**.

The above figures may depict exemplary configurations for the invention, which is done to aid in understanding the features and functionality that can be included in the invention. The invention is not restricted to the illustrated architectures or configurations, but can be implemented using a variety of alternative architectures and configurations. Additionally, although the invention is described above in terms of various exemplary embodiments and implementations, it should be understood that the various features and functionality described in one or more of the individual embodiments with which they are described, but instead can be applied, alone or in some combination, to one or more of the other embodiments of the invention, whether or not such embodiments are described and whether or not such features are presented as being a part of a described embodiment. Thus the breadth and scope of the present invention, especially in the following claims, should not be limited by any of the above-described exemplary embodiments.

Terms and phrases used in this document, and variations thereof, unless otherwise expressly stated, should be construed as open ended as opposed to limiting. As examples of the foregoing: the term "including" should be read as mean "including, without limitation" or the like; the term "example" is used to provide exemplary instances of the item in discussion, not an exhaustive or limiting list thereof; and adjectives such as "conventional," "traditional," "standard," "known" and terms of similar meaning should not be construed as limiting the item described to a given time period or to an item available as of a given time, but instead should be read to encompass conventional, traditional, normal, or standard technologies that may be available or known now or at any time in the future. Likewise, a group of items linked with the conjunction "and" should not be read as requiring that each and every one of those items be present in the grouping, but rather should be read as "and/or" unless expressly stated otherwise. Similarly, a group of items linked with the conjunction "or" should not be read as requiring mutual exclusivity among that group, but rather should also be read as "and/or" unless expressly stated otherwise. Furthermore, although item, elements or components of the disclosure may be described or claimed in the singular, the plural is contemplated to be within the scope thereof unless limitation to the singular is explicitly stated. The presence of broadening words and phrases such as "one or more," "at least," "but not limited to" or other like phrases in some instances shall not be read to mean that the narrower case is intended or required in instances where such broadening phrases may be absent.

What is claimed is:

1. A propulsion energy storage system in a hybrid electric vehicle, the propulsion energy storage system comprising:

a first ultracapacitor pack assembly including a plurality of energy storage cells electrically coupled to each other, the energy storage cells each having a case and at least one terminal, the first ultracapacitor pack assembly configured support each energy storage cell by its respective case;

plurality of terminal heat sinks thermally coupled to each terminal of the plurality of energy storage cells, the plurality of terminal heat sinks configured to transfer heat from its respective terminal to heat transfer fluid;

a first housing configured to enclose the first ultracapacitor pack assembly and mount the first ultracapacitor pack assembly to the hybrid electric vehicle, the housing including a propulsion energy interface to configured to supply power to the hybrid electric vehicle;

a first closed-loop cooling system configured to circulate heat transfer fluid in the housing, convectively transferring heat from the terminal heat sinks, and further configured to reject the transferred heat away from the ultracapacitor energy storage system;

a communication interface to the hybrid electric vehicle, and,

a controller configured to control cooling functions of the first closed-loop cooling system and/or electrical functions of the first ultracapacitor pack assembly.

2. The propulsion energy storage system of claim **1**, wherein the energy storage cells are cylindrical or prismatic in form, having a terminal on each base; and,

wherein the first ultracapacitor pack assembly arranges the plurality of energy storage cells such that their terminals are substantially vertical when mounted on the hybrid electric vehicle.

3. The propulsion energy storage system of claim **1**, wherein the first closed-loop cooling system uses air as its heat transfer fluid.

4. The propulsion energy storage system of claim **3**, wherein the first closed-loop cooling system includes a blower configured to blow air across the terminal heat sinks, and the first closed-loop cooling system further includes a heat exchanger configured transmit heat from the circulating air to an external coolant loop.

5. The propulsion energy storage system of claim **4**, wherein the external coolant loop includes a vehicle cooling system and is configured to circulate vehicle coolant through the heat exchanger of the of the closed-looped cooling system.

6. The propulsion energy storage system of claim **4**, further including a dedicated energy storage cooling supply configured to provide coolant to the heat exchanger and reject the transferred heat away from the ultracapacitor energy storage system; and,

wherein the controller is further configured to control the dedicated energy storage cooling supply.

7. The propulsion energy storage system of claim **1**, wherein the first housing is further configured to direct heat transfer fluid over the terminals such that heat transfer fluid does not bleed out of a predetermined flow path.

8. The propulsion energy storage system of claim **1**, wherein the communication interface is configured to transmit Controller Area Network (CAN) communications between the ultracapacitor energy storage system and the hybrid electric vehicle.

9. The propulsion energy storage system of claim **1**, wherein the communication interface is integrated into the controller.

10. The propulsion energy storage system of claim **9**, wherein the first ultracapacitor pack assembly further includes cell equalization and monitoring, and is communicably coupled to the controller.

11. The propulsion energy storage system of claim **10**, wherein the first ultracapacitor pack assembly further includes overvoltage protection circuitry configured to indicate to the controller when an overvoltage condition has occurred in the energy storage cells.

12. The propulsion energy storage system of claim **11**, wherein the first ultracapacitor pack assembly further includes self-verification circuitry configured to indicate to the controller that the overvoltage protection circuitry is properly connected to the energy storage cells.

13. The propulsion energy storage system of claim **1**, wherein the first ultracapacitor pack assembly further includes a plurality of flexible interconnects that electrically couple the terminals of the energy storage cells, while only introducing nominal loads on the terminals.

14. The propulsion energy storage system of claim **1**, further comprising a temperature sensor communicably coupled to the controller, and configured to measure the temperature associated with the energy storage cells; and,

wherein the controller is further configured to actively control cooling of the energy storage cells responsive to the temperature sensors.

15. The propulsion energy storage system of claim **1**, further comprising a second ultracapacitor pack assembly that is electrically coupled to the first ultracapacitor pack assembly; and,

wherein the first housing is further configured to enclose the second ultracapacitor pack assembly.

16. The propulsion energy storage system of claim **1**, further comprising:

a second ultracapacitor pack assembly similar to the first ultracapacitor pack assembly, and electrically coupled to the first ultracapacitor pack assembly;

a second housing configured to enclose the second ultracapacitor pack assembly and mount the second ultracapacitor pack assembly to the hybrid electric vehicle;

a second closed-loop cooling system (**650**) configured to circulate heat transfer fluid in the housing, convectively transferring heat from the terminal heat sinks (**170**), and further configured to reject the transferred heat away from the ultracapacitor energy storage system (**100**); and

wherein the controller is configured to control cooling functions of the first and the second closed-loop cooling system and/or electrical functions of the first and second ultracapacitor pack assembly.

17. The propulsion energy storage system of claim **1**, wherein the propulsion energy storage is configured to store energy over 500 V with a leakage rate of <5 mA and an isolation voltage of 2500 V, the propulsion energy storage further configured to deliver energy at a peak of 300 A.

18. The propulsion energy storage system of claim **1**, wherein the propulsion energy storage is configured to reject 3 kW of heat.

19. The propulsion energy storage system of claim **1**, wherein the first housing is sealed and protects against the ingress of dust.

20. The propulsion energy storage system of claim **1**, further comprising at least one DC Bus precharge resistor.

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